INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD

(ISSN: 2455-0620)

(Journal Impact Factor: 9.47)

Monthly Peer-Reviewed, Refereed, Indexed Scientific Research Journal

UGC Approved Journal No. - 47793, Index Copernicus IC Value: 86.87

DOIs:10.2015/IJIRMF

International Conference on Research and Innovations (ICRI-2026)

DOIs:10.2015/IJIRMF/ICRI-2026

Conference Special Issue - 66 March - 2026

Organized by :

Asian Research Foundation.
Shinawatra University, Bangkok, Thailand.
Institute of Management and Commerce(IIMC), Osmania University, India.
International Scientific Research Association.
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International Conference on Research and Innovations

Date: 27 – 28 March, 2026

Venue: Shinawatra University, Bangkok, Thailand

Conference Special Issue / Proceedings Issue - 66

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Dr.Chirag Patel

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Asian Research Foundation.
Shinawatra University, Bangkok, Thailand.
Institute of Management and Commerce(IIMC), Osmania University, India.
International Scientific Research Association.
Supported by Eurasian Institute of Science and Technology(EU)
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Published by:
International Journal for Innovative Research in Multidisciplinary Field
(ISSN: 2455-0620) [UGC Journal Number – 47793]
Research Culture Society and Publication.
(Reg. International ISBN Books and ISSN Journals Publisher)
Email: editor@ijirmf.com / rcsjournals@gmail.com
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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD (ISSN: 2455-0620) [UGC Journal Number – 47793]

Research Culture Society and Publication.

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Conference, Seminar, Symposium organization in association/collaboration with different Institutions.

Conference, Seminar, Symposium Publication with ISSN Journals and ISBN Books (Print / Online).

About the organizing Institutions:

The Asian Research Foundation (ARF) is an Internationally oriented organization dedicated to advancing scientific knowledge, innovation, and interdisciplinary collaboration across borders. Founded on the principles of excellence, integrity, and inclusivity, the ARF serves as a platform for researchers, institutions, and policymakers to collaborate on solutions in academic, industrial and corporate fields.

Shinawatra University (SIU), established in 1999, is a premier international institution in Thailand dedicated to innovation, technology, and global academic excellence. With its main "Green Campus" in Pathum Thani and a strategic city campus in Bangkok, SIU provides a multicultural learning environment for students from over 30 countries. The university is distinguished by its research-driven pedagogy and robust international partnerships across disciplines including **Management, Information Technology, Engineering, Nursing, and Liberal Arts.**

Global Rankings & Recognition of SIU.

The institution has achieved significant milestones in international benchmarks, reflecting its commitment to high educational standards:

- **QS Stars Rating:** Awarded **5 Stars for Excellence**, the highest rating for university quality.
- **QS Asia University Rankings 2026:** Ranked **#250** overall in Asia.
- **QS South Eastern Asia Rankings:** Ranked **#61** in the region.
- **QS World University Rankings by Subject 2025:** Ranked **#151-200** in Arts & Design.
- **Global Standing:** Ranked **#713** globally and **#40** in Thailand.

The Indian Institute of Management and Commerce(IIMC) established five decades ago(year 1973) has to its credit some outstanding achievements in the field of Commerce Education in general and Honours course in particular at the Degree level. The college was admitted into grant-in-aid in the year 1980 and it was admitted into Sec.2 (f), 12-B of University Grants Commission in the year 1994 and affiliated to Osmania University. The college was ranked by various magazines like The Week, Outlook, India Today, Education World, Digital Learning and it has established itself as a premier institution in field of commerce education in the country.

'Research Culture Society' (RCS) is a Government Registered International Scientific Research organization. Registered with several United or Government bodies. It is also an independent, professional, non-profit international level organization. RCS-ISRO shall also initiate and setting up new educational and research programs with other international organizations. Society has successfully organized 175+ conferences, seminars, symposiums and other educational programmes at national and international level in association with different educational institutions.

About the Conference :

ICRI-2026 is a good platform to bring together accomplished academicians, scientists, researchers, scholars and students to exchange and share their knowledge, experiences and research results on the aspects of advancements in Science, Agriculture, Engineering, Technology, Business Management, Commerce, Social Sciences, Literature, ELT and Education. This forum can & will spell a scholarly platform to network and discuss the practical challenges encountered and the solutions adopted in their respective domains worldwide. The Conference main Aim is to provide an interaction stage for researchers, students and practitioners from academia and industries to deal with state-of-the-art advancement in their respective fields. The outcome based aim is an ambience that will be instrumental in taking our participants and delegates to the next level of their expertise in their profession. Participants also will visit the city and country as it is a famous tourist attraction.

Objective of the International Conference is to bring together innovative academics, researchers and industrial experts in the field of Scientific, Multidisciplinary Innovation Studies in the Research field to a common platform. The main objective of the scientific conference is to exchange of ideas, discuss issues and views towards the advancement of theory and practices and to create space for presentation of current results of research and scientific work in the field of Sciences, Agriculture, Engineering and Technology, Business Management, Trade, Economy, Social Sciences, Literature, ELT and Education. Conferences such as this provide a valuable opportunity for researchers, academicians and students to share experiences.

Tracks :

- **Track 1 – General – Basic Sciences, Applied Science and Allied Science.**
- **Track 2 – Engineering and Technology.**
- **Track 3 – Business Management.**
- **Track 4 – Commerce / Trade – Economy.**
- **Track 5 – Social Sciences, Law, ELT and Literature.**
- **Track 6 – Education and Physical Education – Sports Science.**

About the Special Issue / Conference Book :

Science, Engineering and Technology cross nearly every facet of modern life and, as problem solvers, engineers are perfectly capable of managing technical activities, mastering innovative ways of science and engineering field, when they spend time and efforts understanding and acting in the field. Scientific and technological innovation, as strategic support to improve social productivity and overall national strength, must be placed at the center for development of any country.

The framework includes engineering and technology as they relate to applications of science. Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Technology is used to include all types of human-made systems and processes.

The special issue / conference proceedings / edited book is a collection of peer-reviewed scientific papers submitted by active researchers in the International Conference on Science, Engineering & Technological Innovation. This book can be helpful to understand the various concepts of Science and Technological Innovation to the researchers and academia.

President's Message

It gives me immense pleasure to collaborate for the **'International Conference on Research and Innovations' (ICRI 2026)** to be held on **Friday, 27th March 2026**. In this modern era, research has become the order of the day, making vital contributions to the fields of Applied Sciences, Engineering, Business, and Education. We are currently navigating a significant innovation era, where the rapid development of technology is expanding our capabilities across both the industrial and service sectors.

I congratulate the **Research Culture Society (RCS)** and the entire team associated with organizing this conference at **Shinawatra University**. By providing a platform for tracks such as *Healthcare Sciences, Commerce & Economy, and Social Sciences*, we are encouraging a multidisciplinary approach to global challenges. This event offers a unique opportunity for scholars to present papers, share poster theses, and engage in meaningful academic discourse.

Shinawatra University is proud of its growing global footprint, recently recognized with a **QS 5-Star Rating for Excellence** and ranked **#61 in the QS South Eastern Asia Rankings**. We value our long-lasting relationship with our international partners and look forward to the innovative ideas that will be shared within our halls.

I wish all the participants and organizers a highly successful and intellectually rewarding conference.

Assoc. Prof. Dr. Zhou Fei

PRESIDENT

Shinawatra University, Pathum Thani, Thailand.

Dr.Jessica C.
Founder President, International Scientific Research Association.
Email : scientificresearchassociation@gmail.com

Message

Dear Colleagues !

I am grateful to co-organizing institutions, all the speakers, committee members and presenters of 'International Conference on Research and Innovations' (ICRI-2026) The overwhelming response to the contributors were acknowledged in very positive manner and its shows that new age is very much eager to work with technical literature. The rising researcher and scholar from various institutions and in-house participants motivate us to improve ourselves.

We are currently in the era of science and engineering revolution, spearheaded by recent developments in engineering, technology and sciences, providing sustainable solutions to various issues.

Here I am delighted that the series of conference on contemporary issues in computer technology has successfully completed its three folds and entered into fourth one, it's all due to the valuable efforts of faculty members of computer science and engineering department.

I extend my best wishes for the editorial team of the special issue; at last, I hope this technological literature interaction will be a source of inspiration to upcoming educationists, technocrats and stakeholders.

Jessica

ICRI - 2026 Conference Head
Founder, International Scientific Research Association

Dr.C. M. Patel

Director, RESEARCH CULTURE SOCIETY

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Message

Dear Professional Colleagues,

It is gratifying to note that Asian Research Foundation. Shinawatra University, Bangkok, Thailand. Institute of Management and Commerce(IIMC), Osmania University, India in collaboration with 'Research Culture Society' (Government Registered Scientific Research organization) are organizing - 'International Conference on Research and Innovations' during 27 - 28 March, 2026.

The aim of the conference is to provide an interaction stage to researchers, practitioners from academia and industries. The main objective is to promote scientific and educational activities towards the advancement of common citizen's life by improving the theory and practice of various disciplines of science and engineering. Provide the delegates to share their new research ideas and the application experiences face to face.

I believe, this International Conference will help in redefining the strong connection between students and academicians from different institutions. An additional goal of this international conference is to combine interests and scientific research related to General Science, Physical Science, Applied Sciences, Engineering and Technology Development to interact with members within and outside their own disciplines and to bring people closer for the benefit of the scientific community worldwide.

My best wishes to the committee members, speakers and participants of this scientific conference ICRI-2026.

Dr.C. M. Patel
Director, Research Culture Society.

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Dr. Chirag Patel, Director – Research Culture Society, Founder Member, Asian Research Foundation,; Program Head, EU.
K.Raghu Veer, Principal, Indian Institute of Management and Commerce, Affiliated to Osmania University, Khairatabad, Hyderabad, India.

Keynote Speakers :

Dr. Sipnarong Kanchanawongpaisan, Deputy Director of the Institute of Multidisciplinary, Postdoctoral and Franchise Program (IPF), Faculty of Engineering and Technology, Shinawatra University, Thailand.
Assoc. Prof. Dr. Thachakorn Komol, Keynote Speaker, Shinawatra University, Thailand.
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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P01 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Effects of Partial Substitution of Commercial Feed with Kakawati (*Gliricidia sepium*) Leaf Meal on the Growth Performance of Broiler Chickens

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Abstract: *This study evaluated the effects of incorporating Gliricidia sepium leaf meal (GLM) into broiler diets on growth performance, feed efficiency, carcass traits, and production index. Four dietary treatments were formulated: T1 (0% GLM), T2 (10%), T3 (20%), and T4 (30%). Each diet underwent proximate analysis, and a 42-day feeding trial to assessed growth performance, feed intake, feed conversion ratio (FCR), mortality, carcass yield, organ weights, and production efficiency index (PEI). Results showed that T1 achieved the highest body weight gain, feed intake, lowest FCR, and PEI, while T2 exhibited comparable results to T1 but slightly have lower performance. Inclusion levels above 10% significantly reduced growth, feed utilization, and survivability ($p = 0.00 < 0.05$), suggesting that reduced palatability and nutrient availability at higher GLM levels limited its growth. Feed intake is positively correlated with body mass gain, but the relationship is not significant ($r = 0.351$, $p = 0.130 > 0.05$), while FCR values indicate no significant difference across treatments ($p = 0.394 > \alpha = 0.05$). Carcass and organ characteristics were unaffected ($p > 0.05$) across treatments. Proximate analysis indicated that T1 closely matched standard feed composition, T2 slightly lower in enSSSergy, while T3 and T4 deviated substantially. T1 is most suitable for the grower phase and acceptable for the finisher phase with added energy, while T2 may serve as a finisher feed with minor adjustments. The study concludes that GLM can safely replace up to 10% of commercial broiler feed without adverse effects on performance. Higher inclusion levels reduce palatability and productivity due to possible anti-nutritional factors. Limiting GLM to 10% and exploring processing methods to mitigate anti-nutrients can promote its use as a sustainable, cost-effective poultry feed ingredient.*

Keywords: *commercial chicken, feed formulation, feed conversion ratio, production efficiency index, proposed framework.*

1.INTRODUCTION

Poultry production is an essential agricultural activity that supports food security and rural livelihoods. However, the rising cost of commercial feeds remains one of the major constraints affecting the profitability and sustainability of smallholder poultry production. Conventional livestock feeds depend heavily on grain-based ingredients that compete with human food sources, contributing to increasing prices and supply instability. As the global population continues to grow, this competition is expected

to intensify, further increasing feed costs and limiting the viability of livestock production systems. The United Nations (2019) projected that feed prices will continue to rise due to the growing demand for raw materials used in both human food and animal feed formulation. Currently, the average cost of commercial pellet feeds ranges from 1,500 to 2,000 pesos (Philippines currency) per sack, posing a significant financial burden on poultry farmers. These challenges have encouraged researchers to explore alternative, locally available feed resources—particularly underutilized plant-based protein sources to reduce dependence on conventional feeds and to support more sustainable production systems. One of these promising resources is *Gliricidia sepium*, locally known as kakawati, a leguminous tree abundant in many parts of the Philippines. Kakawati leaves contain 18–30% crude protein and have demonstrated potential as an effective and sustainable feed ingredient in several livestock species. Kakawati (*Gliricidia sepium*), a leguminous tree species commonly found in the Philippines, has shown potential as an alternative feed ingredient in several animal species. Research studies revealed significant results in using the Gliricidia leaf meal (GLM) as an effective and sustainable component of animal feed due to its high protein content and nutritional benefits. GLM, when used as part of a feed mix for rabbits, goats, and cattle, can replace traditional concentrates like soybean meal without adverse effects (Fasae, Alokan, & Fajemisin, 2014; Akinlade, et al., 2002). In studies on cattle, GLM combined with cassava-based supplements improved average daily weight gain. This substitution reduced feed costs and increased total digestible nutrients, making it a cost-effective solution for smallholder farmers (Winarti, et al.2023).

Protein content in Kakawati (18-30%) varries on the processing and drying, and its improved feed efficiency particularly the inclusion of 5-10% in the feed improve feed conversion ratios (FCR) in both broiler and native chickens and it is cost-effective (Aregheore et al., 2002). Reports also indicate improvements in weight gain and feed efficiency when GLM is used at inclusion levels between 5–10% (Aregheore et al., 2002). Similar findings in poultry suggest that a 5% inclusion level may support acceptable growth performance and reduce feed costs (Oloruntola et al., 2016; Santiago et al., 2013). More recent studies suggest that GLM can replace soybean meal at levels up to 40% without detrimental effects in broilers (Ayoola et al., 2020), although optimal inclusion levels vary widely across studies.

Despite evidence of GLM's potential, notable gaps and inconsistencies remain. Variation in results across studies may be attributed to differences in processing methods (e.g., fresh, dried, fermented), feed form (mash vs. pellet), and inclusion levels. Moreover, kakawati leaves contain anti-nutritional factors (ANFs) such as tannins, saponins, and lectins, which can impair nutrient absorption at high inclusion levels. Processing methods like drying and fermentation are known to reduce ANFs, few studies have compared these methods systematically. Most existing poultry studies have used GLM in fresh or mash form, and the use of kakawati in pelletized feeds especially for broiler diets remains largely unexplored. Pelletizing is known to improve nutrient density, reduce wastage, and enhance feed palatability, which is particularly critical during the early growth stages of broiler chickens. However, limited research exists on how broilers respond to pelletized diets containing higher levels of GLM or to fermented GLM used as a partial substitute for commercial feeds.

Given these gaps, this study aims to evaluate the effects of partially substituting commercial broiler feed with pelletized diets containing 10%, 20%, and 30% fermented dried *Gliricidia sepium* leaf meal. This study is very significant in addressing the pressing challenges faced not only by poultry farmers but also by livestock producers in general, particularly the rising cost of commercial feeds and the scarcity of feed resources during drought conditions. Findings of this research contributes to the advancement of sustainable livestock farming and supports long-term food security, especially under conditions of rising feed prices and seasonal feed scarcity.

2.Materials and Methods

The study was conducted at the researcher's farm located in Napo, Aurora, Zamboanga del Sur, Philippines. The farm covers approximately 10 hectares and provides an ideal environment for poultry

production, being situated away from densely populated areas and free from nearby poultry operations. The experimental period lasted for 42 days (six weeks) using Completely Randomized Design (CRD) to evaluate the effects of partially substituting commercial broiler feed with varying levels of *Gliricidia sepium* leaf meal (GLM). This layout was used since all experimental units (chickens) are assumed to be homogeneous except for treatment. In this manner, chickens are randomly assigned to different treatments without blocking. This approach allows the researcher to scientifically test the effectiveness and safety of these ingredients as feed for broiler chicken. Comparing different groups with controlled variables make precise observations and draw a valid conclusion (Creswell, 2018).

A total of 200 broiler chicks were randomly assigned to four dietary treatments, each representing a different GLM inclusion level:

a) T1: 0% GLM (Control)
b) T2: 10% GLM
c) T3: 20% GLM
d) T4: 30% GLM

A randomized controlled feeding trial was conducted to determine the effects of the formulated GLM-based diets on growth performance, palatability, and carcass characteristics. To facilitate gradual adaptation to the experimental feeds, a two-week transition phase was implemented prior to the main trial. This gradual adjustment minimized feed refusal and digestive stress during diet introduction. After the adaptation period, broiler chickens were fed 100% of their assigned experimental diets (T1–T4) for the remaining four weeks of the study. Feed and water were supplied ad libitum, and standard broiler management practices were followed throughout the trial.

Data were systematically collected to evaluate the effects of GLM inclusion on: a) Growth performance, b) Palatability, c) Carcass quality and internal organ development, d) Dressing percentage, and e) Relative mass of liver, gizzard, heart, and intestine. All collected data were arithmetically and statistically analyzed. Arithmetic analysis was used for mass gain, daily feed intake, feed conversion ratio (FCR), and production efficiency index (PEI). Statistical analysis such as descriptive, correlational, and inferential statistics was used to describe and compare the growth performance, palatability and FCR. Analysis of variance (ANOVA) and Kruskal Wallis was employed to determine significant differences among treatments, and post-hoc tests were conducted where appropriate. Statistical significance was established at $p < 0.05$. Likewise, a proximate analysis of GLM and formulated feeds was conducted to determine crude protein, moisture, ash, crude fiber, and fat content.

Prior to conduct the study, ethical approval for the study was obtained from the institutional animal ethics committee. All procedures involving animals adhered to humane handling guidelines, ensuring appropriate housing, feeding, biosecurity, and care to minimize stress and suffering throughout the experiment.

3.Results

Growth Performance

The growth performance of broiler chickens refers to how well the chickens grow and convert feed into body weight over a given period. In this study the growth performance of the broilers under different treatments (T1-T4)) was measured in terms of body mass gain (BMG). Comparing the growth rate of broiler across treatments, Figure 1 shows that broilers grew best on the control group (0%GLM), having consistently high body mass gain with low variability. This indicates that broiler chickens in this treatment gained weight steadily and predictably. Treatment 2 (10% GLM) on the other hand, shows moderate mean gain but with large variation among replications. Some broiler chickens performed similarly to T1, but others had much lower gains (as low as ~260 g). This suggests that 10% GLM caused inconsistent performance, perhaps some animals tolerated it better than others. However, the inclusion of GLM above 10% consistently depressed growth (T3 and T4), with severe effects.

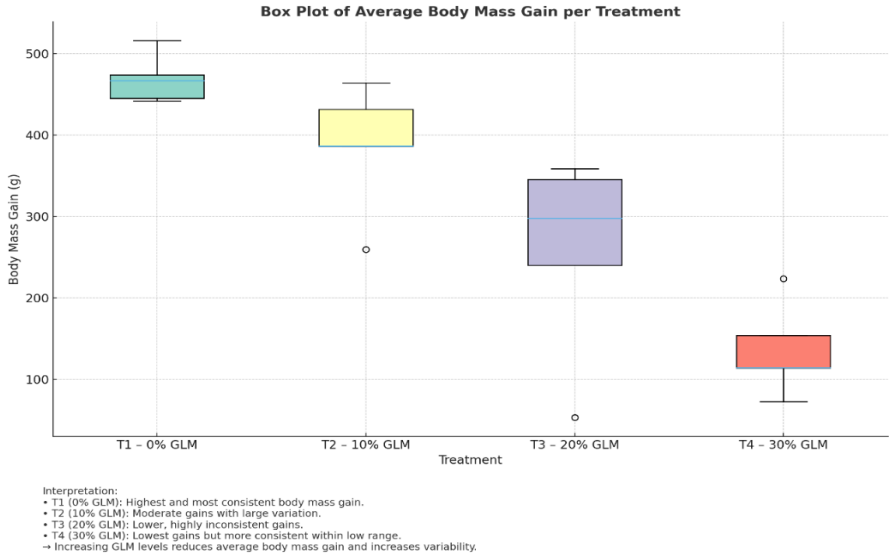

Figure 1. Comparative Growth of Broiler Chicken per Treatment and Replicate

Table 1. Mean, Standard Deviation and Analysis of Variance of the Average Body Mass Gain among Treatments

Treatments	Mean	SD	Description		Body Mass Gain		
					F	Sig. α =.05	Remarks
T1 – 0% GLM	468.7	29.8	With highest gain		16.658	**.000**	**Highly Significant**
T2 – 10% GLM	385.6	77.7	Moderate gain, wider variation				
T3 – 20% GLM	258.9	124.1	Low gain, more inconsistent				
T4 – 30% GLM	135.6	56.9	Very low gain				

The comparative results of the body mass gain across treatments as measured through mean, standard deviation and analysis of variance. As shown in Table 1, there is a clear decreasing trend in mean performance as the percentage of GLM increases (T1>T2>T3>T4). This suggests that the higher the GLM concentration, the lower the gain. The relatively low standard deviation (SD = 62.9) in T1 (0% GLM) indicates stable performance across replications. This confirms that the absence of GLM supports optimal growth or yield. The high value of SD in T3 (124.1) respectively suggesting a variable response of broiler in their fed diet. On the other hand, T4 has relatively moderate SD (56.9) compared to T3, indicating a more consistent response on their diet fed, but the growth performance is consistently poor. In general, the variability pattern is inconsistent, it increases at intermediate levels (10-20%) and decreases again at 30%. These results suggest that 0% is optimal, while any addition beyond 10% leads to diminishing and unstable performance. Hence, from both a statistical and practical standpoint, GLM inclusion beyond 10% is not recommended. On the other hand, the results of the Analysis of Variance of the Body Mass Gain (BMG) per treatment obtaining a p values =.000 indicate that the treatments had a statistically significant effect on Body Mass Gain (BMG) of the broiler chicken, and its effects has significant difference across treatment. This implies that varying levels of GLM significantly influence growth performance.

Palatability

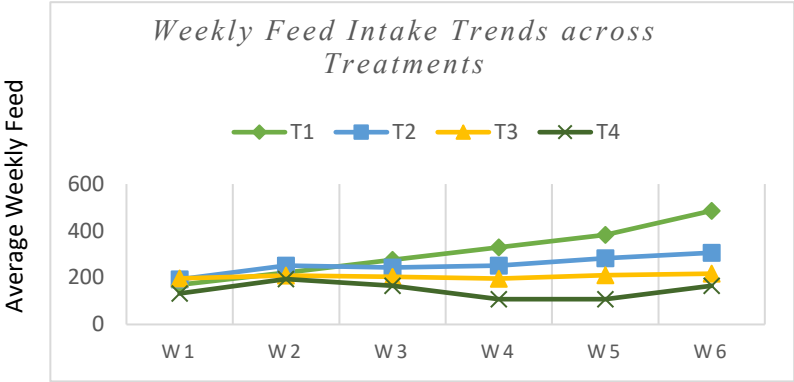

Figure 2. Feeding Pattern per Treatment based on Average Feed Intake
Note. T1 (0%GLM) T2 (10% GLM) T3 (20% GLM T4 (30% GLM)

Generally, the trend shows (Figure 2) that feed intake decreases across treatments. Broilers under Treatment 1 has consistent feed intake across replicates and weeks. This indicates normal feed acceptability and palatability. Likewise, broilers under Treatment 2 shows a moderately high feed intake across weeks but it is much lower compared to Treatment 1—the control group. These results implies that that inclusion of GLM at 10% level started to limit intake possible due to taste or fiber content. In general, among treatments, treatment 4 (T=30%GLM) shows the very poor intake.

Table 2. *Average Weekly Feed Intake (AWFI), FCR and Mortality of Broiler Chickens in 42 days*

Treatments	*Replicate (R)*	Weekly Feed Intake (FI) in grams						± SD	Mortality
		Week1	Week2	Week 3	Week 4	Week 5	Week 6		
T 1 (0% GLM)	R1	1950	2600	3550	4150	4350	5540		2
	R2	1700	2300	2650	3450	4050	4880		4
	R3	1500	1850	2400	2900	3750	4650	**0.477**	3
	R4	1250	1800	2300	2650	3450	4580		4
	R5	2080	2500	2900	3300	3550	4650		2
TOTAL		8480	11050	13800	16450	19150	24300		
AWFI		**1211.43**	**1578.57**	**1971.43**	**2350.00**	**2735.71**	**3471.43**		
FCR		**27.04**	**7.43**	**7.11**	**7.00**	**6.92**	**2.64**		
T 2 (10% GLM)	R1	2550	3500	4300	4700	4900	5055		1
	R2	2900	2900	2800	2950	3500	3720		3
	R3	1400	1850	1400	1900	2250	2725	**0.778**	4
	R4	1400	1500	1400	1600	2100	2305		5
	R5	1400	2800	2250	1400	1400	1520		3
TOTAL		9650	12550	12150	12550	14150	15325		
AWFI		**1378.57**	**1792.9**	**1735.7**	**1792.9**	**2021.4**	**2189.3**		
FCR		**18.85**	**34.38**	**5.76**	**5.63**	**5.36**	**2.70**		
T 3	R1	1400	1700	2100	2100	2100	2170		6
	R2	2100	2250	2150	2100	2100	2170		4

(20% GLM)	R3	1950	2450	2350	2100	2100	2170	**23.02**	4
	R4	2150	2500	2150	2100	2100	2170		7
	R5	2250	1550	1400	1400	2100	2170		10
TOTAL		9850	10450	10150	9800	10500	10850		
AWFI		**1407.14**	**1492.9**	**1450**	**1400**	**1500**	**1550**		
FCR		**26.46**	**18.39**	**27.45**	**24.14**	**6.07**	**20.35**		
T4 (30% GLM)	R1	1600	2450	1900	0	0	0		10
	R2	1600	2350	1300	700	700	785		9
	R3	900	1400	1200	700	700	785	**4.78**	9
	R4	1250	1350	1400	1400	1400	1475		8
	R5	1250	2150	2450	2600	2600	5201		4
TOTAL		6600	9700	8250	5400	5400	8246		
AWFI		**942.857**	**1385.7**	**1178.6**	**771.43**	**771.43**	**1178**		
FCR		**-38.04**	**-9.71**	**-3.82**	**-18.95**	**-80.06**	**-58.40**		
Kruskal-Wallis Result: H = 3.00 Sig. = 0.392 Remarks: No significant difference on FCR									

Note: AWFI = Average Weekly Feed Intake FCR = AWFI / AWG
FCR = Feed Conversion Ratio

In the case of Feed Conversion Ratio (FCR), Table 2 shows that Treatment 1 (0% GLM) has a consistent decrease of their FCR value obtaining a 2.64 FCR at week 6. Treatment 2 (10% GLM) on the other hand, also shows consistent decrease of their FCR value across weeks except in week 2, but still obtained a lower FCR (FCR = 2.70) at week 6 which is almost equal to treatment 1. Treatment 3 (20% GLM) and treatment 4 (30% GLM) shows a fluctuating value of FCR across weeks. Looking into the FCR value of Treatment 1 and Treatment 2 at week 6 (2.64 and 2.70) respectively, it indicated that at week 6 broiler chicken under these treatments shows an efficient feed conversion. However, the negative FCR in treatment 4 indicate that the diet is harmful or severely imbalance. As such, T1 and T2 show good feed conversion ratios with normal trends. T3 shows poor and inconsistent FCR due to mortality and weak growth, and T4 shows biologically impossible, a negative FCR values caused by severe mortality and weight loss indicating diet failure.

The standard deviation results in treatment 1 (SD =0.477) shows a consistently positive growth, efficient and stable. This means that broiler chicken grew well with efficient conversion and this shows that this treatment is the most reliable diet for poultry. In the case of Treatment 2 (10% GLM), although it has almost the same FCR value at week 6, it has higher variability (SD = 0.778), indicating inconsistent response of broilers feed intake due to higher GLM inclusion. This result indicated that at 10% GLM, growth is still possible, but performance is inconsistent. Some broiler chickens convert feed well, while others convert it poorly. This observation may be due to digestibility, palatability issues or variability in nutrient balance. In the case of Treatment 3 (20% GLM) and Treatment 4 (30% GLM) FCR values which is very high and to the extreme negative in treatment 4, it indicates extremely inefficient conversions. The inclusion of 20% and 30% GLM strongly depresses growth or the diet is toxic or unsuitable. In this case, feed is consumed but not efficiently utilized resulting to lose of weight.

Table 3. *Relationship between feed intake and body mass gain across treatments*

Variable	Mean	SD	r	Sig (2 tailed)	Remark
Feed Intake	167.7	174			Correlation is not significant
Average Body Mass	13740	5310	0.351	0.130	

From the statistical results shown in Table 3, the relationship between feed intake (FI) and average body mass gain (ABMG) is positive but not significantly correlated ($r = 0.351$, $p = 0.139$, $p > 0.01$). The absence of a significant relationship between feed intake and growth performance among broiler chickens fed diets containing varying levels of Gliricidia leaf meal (GLM) may be attributed to the effect of anti-nutritional factors and reduced nutrient utilization rather than differences in voluntary feed consumption.

Carcass quality and internal organ development

The carcass quality of broiler chicken as measured by their average dressing percentage (AD%) in Table 4 shows that Treatment 1 (0%GLM) is within or slightly above the normal commercial broiler dressing percentage range (65–75%). Treatment 2 (10% GLM) is comparable to T1(73.65) and still within standard range. This suggests that 10% GLM did not negatively affect carcass yield. However, Treatment 3 (20% GLM) significantly lower than the normal range, showing poor carcass yield at higher GLM inclusion, while Treatment 4 (30% GLM) shows an extremely poor dressing percentage (42.35%), and is below acceptable standards, indicating severe carcass loss, possibly due to high mortality, low body weight, and poor feed conversion.

Table 4. *Carcass Quality through Average Dressing Percentage (AD%)*

Replicates (R)	Treatments (T)			
	T1 (D%)	T2 (D%)	T3 (D%)	T4 (D%)
R1	68.73	69.272	63.78	0
R2	80.92	67.73	92.71	67.5
R3	74.07	68.98	64.60	64.29
R4	70.15	69.99	75.91	80
R5	89.48	92.22	0	0
AD(%)/Treatment	**76.67**	**73.64**	**59.40**	**42.36**

Note: *D% (Dressing %) = eviscerated carcass mass/live mass x100*
AD% = Ave Dressing %/replicate/treatment

Table 5 shows both the descriptive analysis and analysis of variance comparing the dressing percentage (D%) across treatments. Descriptive results showed that the treatments varied in their mean values, ranging from 42.36 to 76.67, with an overall mean of 63.01. Treatment 1 recorded the highest mean value (76.67 ± 8.58), followed by Treatment 2 (73.64 ± 10.42), while Treatment 4 had the lowest mean (42.36 ± 39.11). This suggests that the experimental factor influenced performance numerically, with decreasing trends observed as the treatment level increased. However, the high variability, particularly in Treatments 3 and 4, (SD =35.20 and 39.11) indicates that the responses were inconsistent among replicates. The overall standard deviation (SD = 28.56) indicates variability among treatments.

Table 5. *Comparative analysis of carcass quality in terms of dressing percentage, among broiler chickens fed diets with varying inclusion levels of Gliricidia sepium leaf meal (GLM)*

Descriptive Analysis				ANOVA					Remark
Treatments	Mean	SD		Sum of squares	df	Mean Square	F	Sig.	
treatment 1	76.67	8.58		3695.43	3	1231.81	**1.670**		

treatment 2	73.64	10.42	Between Groups						No significant difference
treatment 3	59.40	35.20	Within Groups	11803.93	16	737.74		**.213**	
treatment 4	42.36	39.11							
Total	63.01	28.56		15499.36	19				

The one-way analysis of variance (ANOVA) shown in Table 5 indicates that the differences among treatment means were not statistically significant ($F = 1.670$, $p = 0.213$, $\alpha = 0.05$), since the computed p-value (0.213) is greater than 0.05. This means that although numerical differences existed among the means, these differences could be attributed to random variation rather than the effect of the treatments themselves. In other words, the treatments did not significantly affect the measured variable within the experimental conditions. The absence of significant differences may be attributed to several possible factors. One explanation is the high within-group variability (Mean Square = 737.74), which may have masked potential treatment effects.

Relative mass of liver, gizzard, heart, and intestine

Quantitative measurements of internal organs such as the liver, gizzard, and intestine are critical indicators of the quality and effectiveness of formulated feeds in poultry. Organ mass reflects the physiological response of broilers to different dietary treatments and provides insights beyond growth performance alone.

Table 6. *Relative Organ Mass of Broiler's Internal Organ across Treatments and its Mean, Standard Deviation (SD) and ANOVA results*

Replicates	Internal Organs	Treatments				ANOVA RESULTS		
		T1	T2	T3	T4			
		Rel. Mass (%)	Rel. Mass (%)	Rel. Mass (%)	Rel. Mass (%)	F	Sig	Remark
R1	Liver	6.15	5.66	4.72	--			
	Gizzard	6.56	6.24	5.33	--			
	Intestine	15.64	12.5	12.06	--			
R2	Liver	7.14	5.53	5.69	4.17			
	Gizzard	8.30	6.43	8.24	5			
	Intestine	16.39	13.1	15.65	13.3			
R3	Liver	6.77	5.02	5.36	5			
	Gizzard	6.92	5.28	5.11	6.4			
	Intestine	17.8	14.25	15.65	14.3			
R4	Liver	5.04	7.22	6.33	5.33			
	Gizzard	5.43	5.84	6.76	6			
	Intestine	12.79	13.77	16.07	10			
R5	Liver	4.81	4.44	--	--			
	Gizzard	5.5	5.42	--	--			
	Intestine	16.76	15.83	--	--			
Mean	Liver	5.98	5.57	4.42	2.90	2.420	0.104	**No significant difference**
	Gizzard	6.54	5.84	5.09	3.48	1.594	0.230	
	Intestine	15.88	13.89	11.89	7.52	2.14	0.095	
SD	Liver	1.03	1.04	2.54	2.68			
	Gizzard	1.18	0.49	3.11	3.22			
	Intestine	1.89	1.27	6.84	7.04			

Note. Relative mass (%)=Organ mass (g)/Live mass(g)×100

Table 6 shows the comparison of the broiler's internal organ average relative mass, mean and standard deviation across treatments. The results determine how varying levels of Gliricidia Leaf Meal (GLM) in the formulated feeds influence digestive organ development. Such measurements complement carcass and growth performance data, offering a holistic evaluation of feed effectiveness and the potential benefits or drawbacks of GLM as a dietary supplement. The results shows that the relative mass of liver across treatments per replicate slightly varies indicating a variation of their metabolic workload. Among treatments, treatment 1 has a consistent highest relative mass of liver except for the replicate 4. The same trend is also observed in the gizzard and intestine relative mass. However, there is no significant difference of the relative mass of gizzard, liver and intestine across treatment ($p>0.05$).

Production Efficiency Index

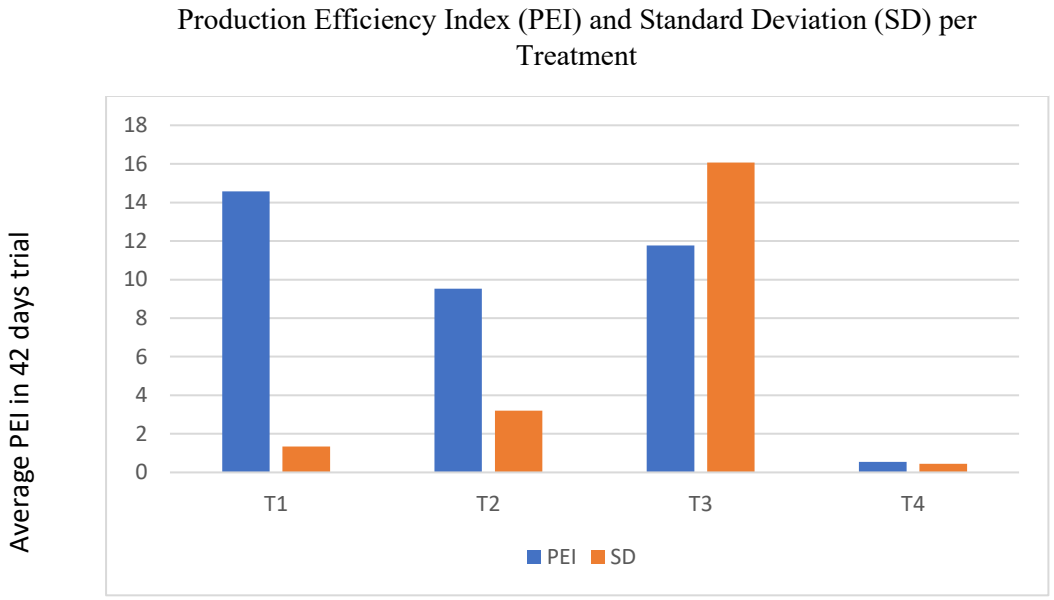

Figure 3. Production Efficiency Index of Broiler Chicken fed with GLM diet

Comparing the four treatments (T1 > T2 < T3 > T4) as shown in Figure 3, T1 shows moderate performance indicating consistently higher means and smaller variation compared to the other treatments. T2 shows best in replicate 1 (PEI = 14.640) but the rest replicates shows heavily reduce PEI. This result indicate that performance can approach control levels (T1), but inconsistent. For treatment 3 (20% GLM) and treatment 4 (30%), production efficiency collapse. Treatment 3 level is unsuitable for broilers while treatment 4 totally unsuitable. From these results it can be said that, 0–10% GLM can be tolerated (though 10% is risky), but 20–30% GLM makes the diet commercially and biologically non-viable. All of these values are far below the commercial benchmark (200–300+). This is due to the fact that the experimental trial was more of a research pen study (with high stress, mortality, or dietary imbalances), rather than optimized commercial conditions.

Table 7 shows the overall production performance, indicating T1 has the best overall performance. It is also noted that mortality increased sharply as GLM inclusion rose above 10%, and livability dropped from ~70% (T1–T2) to ~20% (T4). Similarly, FCR worsened (increased) with higher GLM inclusion, showing poorer feed efficiency, PEI is still far from the standard but was highest in T1, slightly lower in T2 compared to T1, and dropped drastically in T4. Overall, 0–10% GLM inclusion maintained good broiler performance, while ≥20% GLM severely affected survival, growth, and efficiency.

Table 7. *Overall Production Performance Summary*

Treatment	Mean Mortality (%) ±SD	Mean Livability (%) ±SD	Mean FCR ±SD	Mean PEI ±SD	Interpretation
T1 (0% GLM)	30.0 ± 9.49	70.0 ± 9.49	**5.20± 0.477**	**14.571± 1.35**	Best overall performance — low mortality, efficient feed use, and high PEI.
T2 (10% GLM)	32.0 ± 14.14	68.0 ± 14.14	**5.00± 0.778**	**9.535± 3.20**	Slightly higher mortality, low FCR than T1, but low PEI, but still good productivity.
T3 (20% GLM)	62.0 ± 24.49	38.0 ± 24.49	**14.89± 23.02**	**11.768± 16.07**	High mortality and inconsistent results; performance unstable across replicates.
T4 (30% GLM)	80.0 ± 22.36	20.0 ± 22.36	**14.02± 4.78**	**0.504± 0.45**	Extremely poor livability and efficiency; diet likely too limiting.

The proximate composition of the formulated feeds used as the experimental diets is presented in Table 10. The results showed that increasing inclusion levels of Gliricidia leaf meal (GLM) from 0% to 30% resulted in notable changes in nutrient composition. Crude protein, and crude fat content decreased progressively (T1 > T2 > T3 > T4).This reduction reflects the low protein and lipid content of *Gliricidia sepium* foliage relative to conventional feed ingredients. Overall, the results indicate that increasing GLM inclusion enhances dietary fiber and mineral content but reduces fat and energy density, with a modest decline in crude protein.

Table 10. Proximate Analysis Results of the Formulated Feeds

Composition	Treatment 1 (0% GLM)	Treatment 2 (10% GLM)	Treatment 3 (20% GLM)	Treatment 4 (30%GLM)	Standard			Typical Range
					Leeson, S., & Summers, J. D. (2009). National Research Council. (1994).			
					Starter	Grower	Finisher	
Crude fat	2.81	1.78	1.68	1.15	5-7	5-7	5–8	5–8
Crude fiber	2.08	2.18	2.58	4.40	3-5	3-5	3–5	3–5
Moisture content	13.36	12.92	14.35	10.48	≤12	≤12	≤12	≤12
Crude ash	4.92	5.68	6.06	8.29	5–7	5-7	4.5–6.5	4.5–7
Crude protein	16.36	14.28	14.30	14.40	21-23	19–21	18–20	16–23

4.Discussion

Growth Performance of Broiler Chicken

The growth performance of broiler across treatments varies significantly (F = 16.658; p = 0.000), indicating that control group (0%GLM), having consistently high body mass gain with low variability. This indicates that broiler chickens in this treatment gained weight steadily and predictably. On the other hand, the moderate mean gain in Treatment 2 (10% GLM) signifies variation among replications. Some broiler chickens performed similarly to T1, but others had much lower gains (as low as ~260 g). This suggests that 10% GLM caused inconsistent performance, perhaps some animals tolerated it better

than others. However, the inclusion of GLM above 10% consistently depressed growth (T3 and T4), with severe effects. According to the study of Ahmed et al. (2023), optimized nutrient-dense diets significantly increased weekly weight gain, while lower-quality diets led to stagnation after 4-5 weeks due to reduced feed conversion efficiency. This supports why T1 and T2 show higher gains, likely representing more balanced or enriched treatments. However, all treatments do not show consistent growth increase, instead growth depression was observed. Growth depression can be due to feeding management, environmental stress and recovery. This observation might due to the usage of single-feed regimens during the feed trial cycle.

The statistically significant difference on Body Mass Gain (BMG) of the broiler chicken across treatments implies that varying levels of GLM significantly influence growth performance. These significant differences are notable between Treatment 1 and 3 (0% GLM & 20% GLM), Treatment 1 and 4 (0% GLM & 30% GLM); and between Treatment 2 and 4 (10% GLM & 30% GLM) based on the Tukey HSD post hoc analysis. Findings of this study are aligned with the findings of several previous studies. Aregheore (2002) claimed that increasing levels of Leucaena leucocephala leaf meal in livestock diets reduced weight gain due to tannins and mimosine toxicity. Oladunjoye and Ojebiyi (2010) observed similar trends when substituting maize with cassava peel meal indicating that moderate inclusion improved growth slightly, but higher levels depressed performance. Esonu et al. (2006) found that broilers fed with increasing *Moringa oleifera* leaf meal had reduced feed intake and body weight gain at higher levels due to fiber content and anti-nutrients. These findings align closely with the findings of this study wherein the moderate inclusion (10%) caused variable reduced gain, while the 20-30% inclusion led to sharp declines and even negative growth. The larger variance between group as compared to variance within group indicates that GLM level is the dominant factor affecting growth. This pattern suggests that the presence of GLM in the diet or treatment medium exerts a dose-dependent inhibitory effect on growth. The reduction in body mass gain at higher GLM levels may be attributed to the presence of anti-nutritional compounds or decreased nutrient bioavailability, which interferes with normal metabolic and physiological functions.

Moreover, research findings of Oloruntola (2018) claimed that broilers fed with 0%, 5%, and 10% GLM over 56 days, the 5% inclusion supported normal growth, feed intake, carcass yield, and health parameters. Higher levels (10%) reduced performance metrics and elevated some organ weights and white blood cell counts. This study supports the current findings that excessive inclusion of GLM can adversely affect growth performance. Therefore, it can be concluded that GLM levels beyond 10% significantly impair growth, while the control treatment (0% GLM) yields the best and most consistent performance. The results highlight the importance of optimizing GLM inclusion levels to prevent negative growth outcomes and ensure efficient utilization of nutrients.

Palatability of Formulated Feeds

The formulated feed palatability was determined through "No-Choice test Method" or single-bowl (one-pan) test or monadic—a standard protocol in palatability research with a long history of use (Markwell & Parkin, 2015), as measured by the feed intake of the broilers. According to Roura, Iqbal, & Navarro (2025), this method is good for long-term acceptability/production effects. No-choice feeding trials over days/weeks, cumulative voluntary intake, body weight gain, FCR, and morbidity/mortality is the best way to measure palatability. Low intake + poor performance indicates poor acceptability or digestibility (Mbajiorgu, Ng'ambi, & Norris, 2011; Roura, Iqbal, & Navarro, 2025). This study used the feed intake, feed conversion ratio and mortality as the parameters in determining the palatability of the formulated feeds.

Based on the results of the study, T1(0% GLM) the control group provide baseline performance of the broiler chickens giving with best feed intake across treatments. On the other hand, T2 (10% GLM)

shows a possible safe inclusion level considering its slight depression that could be considered acceptable intake. However, T3 (20%GLM) shows significant reduction maybe due to negative effects of fiber and ANFs, while T4 (30%GLM) shows severe depression that could indicate that the inclusion of 30% GLM in poultry diets is unfit for practical use. These findings align with many studies mentioned above and recommend low levels (≤ 10%) GLM inclusions to avoid adverse effects on feed intake and animal performance. GLM can only be tolerated up to 10% inclusion in diets without drastically affecting feed intake. Beyond this level, palatability issues, anti-nutritional factors, and excessive fiber significantly reduce feed consumption, consistent with findings from other leaf meal studies (Owens, et al., 2012; Onu & Aniebo, 2011; Ogbuewu et al. (2012). As such, the results of this study imply that GLM can only be tolerated up to 10% inclusion in diets without drastically affecting feed intake. Beyond this level, palatability issues, anti-nutritional factors, and excessive fiber significantly reduce feed consumption. This indicates that higher level of GLM will reduced palatability and nutrient utilization.

In the case of Feed Conversion Ration (FCR), Treatment 1 (0% GLM) and Treatment 2 (10% GLM) shows an efficient FCR at week 6, having a consistent decrease of their FCR. The standard deviation results in treatment 1 shows a consistently (SD =0.477) positive growth, efficient and more stable. This means that broiler chicken grew well with efficient conversion and this shows that this treatment is the most reliable diet for poultry. In the case of Treatment 2 (10% GLM), although it has almost the same FCR value at week 6, it has higher variability (SD = 0.778), indicating inconsistent response of broilers feed intake due to higher GLM inclusion. This result indicated that at 10% GLM, growth is still possible, but performance is inconsistent. Some broiler chickens convert feed well, while others convert it poorly. The inclusion of 20% and 30% GLM strongly depresses growth or the diet is toxic or unsuitable, having a highest mortality rate. In this case, feed is consumed but not efficiently utilized resulting to lose of weight. Generally, T4 is the worst performing treatment, while T1 and T2 is the best performance treatment. Thus, GLM can only be included safely at ≤10% in broiler diets. Beyond this level, growth performance and feed efficiency collapse, making the diet unsuitable.

Studies have shown that high GLM reduces voluntary intake, and antinutritional compounds (tannins, saponins, phenolics) further depressed growth. These compounds (ANF's: tannins and saponins) are moderately found in GLM. Ogbuewu et al. (2012), linked tannins and saponins to poor feed utilization and reduced protein digestibility. Aside from these compounds feeding quality, feeding program, health status, environment, and management also affects the FCR. On the other hand, according to Esonu et al. (2001) and Akinmutimi (2004), inclusion of leaf meals beyond 10% reduced growth and worsened FCR. Ani and Okorie (2005), also found that rabbits tolerated GLM up to 10% with no major growth issues, but performance declined sharply at 20–30%.

Generally, the FCR values shown in this study are much higher than commercial terms considering the trial was small-scale (only 200 broilers) and pen trial which is not optimized for commercial performance. Another consideration is the environment and dietary factors since the formulated feeds fed on broiler was in single type all through the experimental trial, and based on the proximate analysis results of the formulated feed, the feed is best suited as grower feeds. But, despite of this single type fed treatment, the relative differences between treatments are valid; T1 is the best, T2 is borderline while T3 and T4 is unacceptable. The comparison of the FCR values across treatments shows no significant difference ($p = 0.394 > \alpha = 0.05$), despite of T1 and T2 lower FCR value compared to T3 and T4. This implies that GLM inclusion affects the feed conversion of the broiler chickens due to antinutritional factors present in GLM such as tannins and saponins (Ogbuewu et al. 2012). Likewise, this results also aligned with the research findings of Esonu et al. (2001) and Akinmutimi (2004).

Relationship of Feed Intake and Body Mass Gain

The relationship between feed intake (FI) and average body mass gain (ABMG) is positive but not significantly correlated ($r = 0.351$, $p = 0.139$, $p > 0.01$). This result implies that feed intake will not directly influence the body mass gain of the chicken but rather the nutritional content of the feeds. *Gliricidia sepium* leaves contain tannins, saponins, and phenolic compounds that can form complexes with dietary proteins and digestive enzymes, thereby reducing protein digestibility and nutrient availability to the bird (Odunsi, 2003; Esonu et al., 2001). Consequently, broiler chickens may consume comparable amounts of feed but derive less usable nutrients for tissue synthesis and growth, resulting in similar feed intake values but differing body weight gains or feed conversion efficiencies. Moreover, the high crude fiber content of GLM can reduce the dietary energy density and increase gut fill, limiting nutrient absorption efficiency even when intake is maintained (Aderinola et al., 2013; Okukpe et al., 2020). This suggests that feed intake alone may not be a reliable indicator of performance when the digestibility or metabolizable energy of the diet is compromised by fibrous or tannin-rich leaf meals.

Additionally, palatability and adaptive feeding behavior might have contributed to the non-significant variation in feed intake across treatments, as broilers are capable of adjusting to moderate inclusion of unconventional feedstuffs without substantial changes in consumption (Ekenyem & Madubuike, 2006). Similar findings have been reported by Agbede and Aletor (2003) and Olabode et al. (2019), who observed no significant changes in feed intake despite reduced nutrient utilization efficiency in broilers fed diets containing tropical leaf meals. Therefore, the lack of a significant correlation between feed intake and growth performance in this study could reflect physiological and nutritional adjustments by the broilers, as well as potential experimental variability that masked subtle relationships.

However, findings of this study do not conform with the observations of Adeniji et al. (2012), who reported that increasing feed intake significantly improved body weight gain and feed conversion efficiency in rabbits, indicating a direct and positive relationship between nutrient intake and growth performance. Similarly, Ovie and Eze (2013) found that higher feed intake was positively correlated with body mass gain in *Clarias gariepinus*, suggesting that nutrient availability directly drives somatic growth. The contrast between these results and the present study indicates that, in diets containing Gliricidia leaf meal, nutrient utilization efficiency rather than the quantity of feed consumed plays a more critical role in determining growth performance.

Carcass Characteristics and Internal Organ Development

Carcass quality assessment is an essential indicator of the effectiveness of formulated feeds in broiler production, as it reflects not only growth performance but also the efficiency of nutrient utilization. Parameters such as dressing percentage and visual grading provide practical measures of how dietary treatments influence muscle development, fat deposition, and overall market value of the birds. Thus, evaluating carcass quality ensures that feed formulations are assessed not only for growth outcomes but also for their economic and consumer acceptability in poultry production.

From the results, Treatment 1 (0%GLM) is within or slightly above the normal commercial broiler dressing percentage range (65–75%). Treatment 2 (10% GLM) is comparable to T1(73.65) and still within standard range. This suggests that 10% GLM did not negatively affect carcass yield. However, Treatment 3 (20% GLM) significantly lower than the normal range, showing poor carcass yield at higher GLM inclusion, while Treatment 4 (30% GLM) shows an extremely poor dressing percentage (42.35%), and is below acceptable standards, indicating severe carcass loss, possibly due to high mortality, low body weight, and poor feed conversion. These results are consistent with the report of Ani and Okorie (2005) stating that 10% GLM inclusion did not affect carcass yield in rabbits, but higher levels reduced performance and carcass traits. Onu and Aniebo (2011) also found out that poultry fed

with high leaf meal diets reduces its dressing percentage due to fiber and anti-nutritional factors. Tannins and saponins impair protein utilization, leading to lower muscle deposition and poor carcass yield (Ogbuewu, et al. 2012). According to Oloruntola (2018), up to 5% GLM supported normal carcass yields and blood profiles, while 10% increased organ weights and white blood cell counts. Thus, high GLM inclusion severely compromises carcass quality, making such levels unsuitable for broiler production.

Although Treatment 1 and 2 shows good carcass quality, it does not show significant difference across treatments ($F = 1.670$, $p = 0.213$, $\alpha = 0.05$). This means that although numerical differences existed among the means, these differences could be attributed to random variation rather than the effect of the treatments themselves. These findings are in line with those of Onimisi et al. (2010) and Bamgbose et al. (2012), who similarly reported no significant differences in growth or yield parameters when moderate levels of alternative feed ingredients or treatments were applied. Onimisi et al. (2010) also found that replacing conventional feed components with Moringa oleifera leaf meal up to 10% inclusion produced numerical but non-significant effects on broiler performance. Likewise, Bamgbose et al. (2012) observed that the inclusion of Leucaena leucocephala leaf meal in rabbit diets led to non-significant variations in weight gain, suggesting tolerance to moderate inclusion levels without adverse impact.

On the other hand, carcass quality through visual grading in terms of carcass conformation, fat deposition, skin and feather condition, and defects, it shows that Treatment 1 and 2 has grade A (premium quality) quality in some replicates while the rest of the treatments are in grade B (average). In practical implication, we can say that GLM inclusion above 10% compromises carcass quality, particularly muscle development and fat cover, even if external defects remain absent. This observation is due to the presence of tannins and saponins in leaf meals that can impair protein and lipid utilization, reducing muscle and fat deposition (Ogbuewu, 2012), and visual carcass grading standards emphasize that fat finish and conformation are key determinants of Grade A; poor muscle and low fat that push carcasses to lower grades (USDA, 1996). Arifin and Hironaka, et al. (2024) research findings pointed out that low inclusion levels (commonly $\leq$ 5–10% depending on species and processing) of leaf meal in broilers diet often have no negative effect or can slightly improve some parameters, but higher inclusion levels tend to reduce live weight, dressed weight and fat deposition, producing poorer carcass conformation and lower dressing percentage. This pattern supports the visual grading results of this study where Conformation (CC) and Fat Deposition (FD) scores fall as GLM inclusion increases. The decline in muscling and finish at higher GLM levels is consistent with research reports that tropical leaf meals contain anti-nutritional factors (tannins, saponins) and high crude fiber, which reduce protein digestibility and dietary energy availability in monogastric poultry (Herzig et al., 2021; Ogbuewu et al., 2012). These results suggest maintaining GLM at $\leq$10% or applying processing/enzyme treatments before higher inclusion to avoid compromised carcass quality. However, in this study, despite of the fermentation and drying of GLM prior to inclusion in the formulated feed, growth performance is still low compared to standard due to misfeeding management. The study of Rahoma (2023), concluded that phase feeding doesn't compromise broiler performance but significantly reduces fat deposition and overall feed intake, offering a more cost-effective approach than single-phase feeding. Feeding management strongly affects broiler growth. Poor early nutrition (starter phase) limits muscle fiber development, which cannot be fully compensated later (Tikate, et al., 2020).

In the case of internal organ development such as gizzard, heart and intestine, the results show no notable damages occurred and inconsistent sizes. However, Treatment 1(0% GLM) and 2 (10% GLM) has bigger sizes and higher mass compared to Treatment 3 (20% GLM) and 4 (30% GLM). Olugbemi, Mutayoba, and Lekule (2010), found that the gizzard weights of broilers decreased as the inclusion of Moringa oleifera leaf meal increased, attributing the change to reduced feed intake and digestive

adaptation. Bamgbose et al. (2012) noted that excessive inclusion of Leucaena leucocephala leaf meal caused a decline in liver size, likely due to the liver's role in detoxifying anti-nutritional compounds. Nkukwana et al. (2014), reported that high inclusion levels of Moringa oleifera in broiler diets reduced intestinal length and weight, suggesting a physiological adjustment to lower nutrient absorption capacity. Likewise, Afuang et al. (2003) noted that the incorporation of high levels of herbal leaf meals altered intestinal morphology and reduced absorptive surface area, leading to lower growth rates, in which Gliricidia septum is considered as herbal plant. In general, the descriptive results of this study demonstrate that liver, gizzard, and intestinal weights decreased progressively with increasing treatment levels of GLM, suggesting a dose-dependent inhibitory effect of the treatment on organ development. However, its effects do not show a statistically significant difference across treatment.

Production Efficiency Index

Production efficiency index (PEI) is a combined measure that includes growth rate, feed efficiency, survival, and rearing time. PEI is a performance metric that measures how efficiently a production process turns inputs into outputs. From the results, although Treatment 1 has the highest PEI, followed by Treatment 2, the PEI values observed are still notably smaller than typical commercial broiler PEI reported under intensive systems. This implies that major issues are present, such as significant losses, machine idle time, or quality problems may exist (Aviagen, 2019, Leeson and Summers, 2009). Similar challenges have been reported in small-scale or health-stressed flocks, where high mortality and reduced feed efficiency markedly depress PEI/EPEF (Willems, et al. 2013; Abudabos, et al. 2017). Management and dietary interventions can strongly influence FCR and PEI. Dibner and Richards (2005) and Wang, et al. (2017) confirmed that the inclusion of antibiotic growth promoters or functional feed additives (enzymes, probiotics, chromium, glutamine) has been shown to reduce FCR and improve livability, thereby raising PEI. Esonu et al. (2006) and Oladunjoye and Ojebiyi (2010), reported that increasing levels of unconventional plant-based feed materials led to reduced production efficiency due to limited nutrient availability and higher fiber content. Similarly, Akinmutimi (2004) observed that excessive inclusion of Leucaena leucocephala and Mucuna pruriens leaf meals in livestock diets significantly decreased production efficiency, citing anti-nutritional factors as the primary cause. The current results follow a similar trend, suggesting that moderate inclusion levels may be tolerated, but higher levels lead to reduced production performance.

5.Conclusion and Recommendation

This study evaluated the effects of incorporating *Gliricidia sepium* (Kakawati) leaf meal (GLM) into pelletized broiler feeds at varying inclusion levels. Results showed that a 10% GLM substitution achieved comparable growth performance and carcass yield to standard feeds, while higher inclusion levels (20–30%) led to reduced feed intake, poorer feed conversion, higher mortality, and lower production efficiency. Generally, incorporating up to 10% GLM in broiler feeds offers a cost-effective and environmentally sustainable alternative to conventional protein sources. Its use supports local feed resource utilization and promotes responsible, eco-friendly poultry production—demonstrating that sustainable feeding practices can align with commercial productivity and profitability.

As such, it is recommended that further study can be conducted addressing the limitations and gaps of this present study. More variables and parameters can be investigated and long-term feeding trials will be considered covering the starter, grower, and finisher phases to evaluate the effects of GLM inclusion on overall performance, carcass quality, and animal adaptability.

Proposed Framework for Developing Standardized Guidelines and Halal Compliance for GLM-Based Feed Formulation

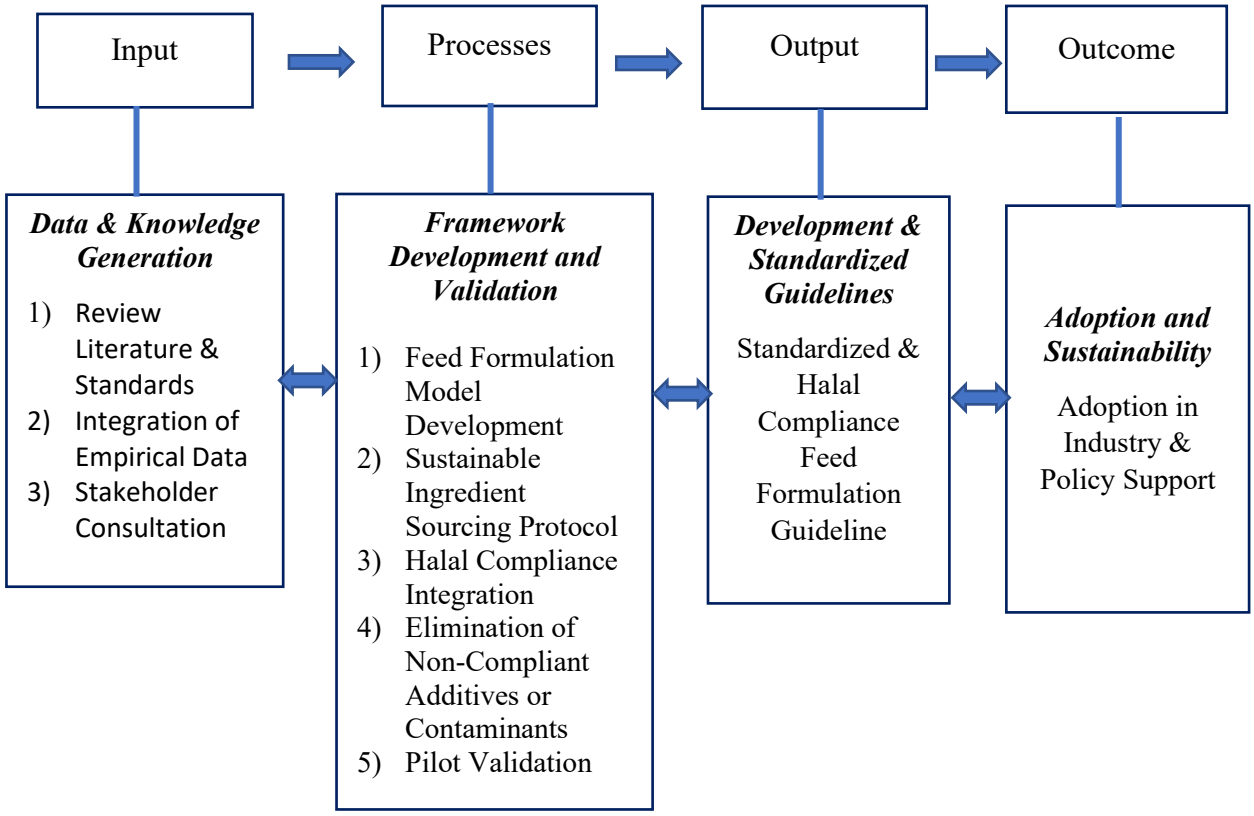

Figure 4. *Schematic Diagram of the Proposed Framework for Standardizing and Ensuring Halal Compliance GLM-Based Feed Formulation*

The proposed framework (Figure 4) presents a systematic approach to developing standardized and Halal-compliant feed formulations utilizing *Gliricidia sepium* leaf meal (GLM). It is composed of four interrelated stages: (1) Input Stage, which establishes the data and knowledge foundation; (2) Process Stage, focusing on framework development and validation; (3) Output Stage, which involves the creation of standardized guidelines; and (4) Outcome and Application Stage, which emphasizes adoption and implementation within the feed industry.

The realization of this proposed framework represents a potential breakthrough for both the agricultural and economic sectors in the Philippines. Formalizing the use of *Gliricidia sepium* as an alternative protein source, advances feed self-sufficiency, promotes sustainable livestock production, and supports the Halal feed market. Furthermore, it encourages continued research, farmer education, and collaboration among government agencies, industry players, and academic institutions to maximize the utilization of locally available feed resources and strengthen food security in the region.

Acknowledgement
I sincerely and wholeheartedly express my deepest gratitude to my thesis adviser, Dr. Jane Tranquilan, for her invaluable guidance, patience, and encouragement throughout the course of this study. Her expertise and unwavering support have been instrumental in the completion of this research.

My profound appreciation also goes to my panel members—Dr. Jesse Jay Villanueva, Dr. Josephine N. Nocon, and Dr. Prechiel A. Barredo—for their insightful comments, constructive suggestions, and

academic guidance that greatly enhanced the quality of this work. Likewise, I extend my heartfelt thanks to Dr. Emma Obalan, my statistician, for her assistance and expertise in the statistical analysis, which significantly contributed to the accuracy and reliability of this study's findings.

To all who have supported and guided me in various ways, I am deeply grateful. Your encouragement and contributions have made this research journey both meaningful and fulfilling.

Above all, my deepest praise and gratitude are offered to our gracious Father in Heaven, whose divine guidance, wisdom, and blessings made everything possible. Without Him, this endeavor would not have been realized.

Conflict of Interest

The authors declare no conflict of interest.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P02 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Cosmetic indulgence implemented by the Ancient India Courtesan

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Abstract : since ancient times, there has been literary and archaeological evidences about the *Ganikaa* (courtesan). The bronze figurine of a dancing girl found at Mohenjo-daro in the Indus Valley prompts discussions about whether she was a dancer/ courtesan or a Ganikaa. This is one of the earliest form of any such archaeological findings. In the *Rigveda, Ganika* is referred to by names like *Hasra, Agru, and Sadharana*. In the *Atharvaveda,* she is called *Pucchali* While *Yajurveda* mentions *Sadharana and Samanya*. The *Jataka* stories include names like *Rupadasi, Vanadasi,* and Veshi, on the *Vinaya Pitaka* refers them as *Muhutiya.* The Ganika is the focus of an entire chapter in the *Arthashastra* titled *Ganikadhyaksha.* Many names similar to *Ganikaa* appear throughout the Epics and *Puran,* including *Kulata, Swadhina,* and *Swarini,* however the *Ganikaa* had a unique and Significantly alienated authority role. Works such as the *Kamasutra, Mrcchakatika, Shringar Shatak, Hitopadesha, Kathasaritsagara*, and *Kala Vilas* all have remark Have remarks on the mention the *Ganikaa.* Texts like *Kala Vilas* and *Mrcchakatika* contain lists that describe the characteristics of a *Ganikaa.* Being a *Ganikaa* was a respected position in ancient India. Literary sources highlight the qualities, duties, advantages benefits, drawbacks, and rights of the *Ganikaa*. Some *Ganikas* later in life took on the role of a *Buddhist Upasika* (female devotee). A similar theme is illustrated by the story of *Sudasana* in the *Their gatha.*

This paper throws light on the understudied characteristics and lives of such anointed ancient courtesans noted as *Ganikaa.*

Keywords: Yakshini, The 64 Arts, Amrapali, Vasantasena, Ganika, Cosmetics.

1.INTRODUCTION

The word "*Ganika*" is derived from "*Gana*" or "group." Its original meaning is one over whom the entire group has authority. "*Ganika*" is the feminine form of "*Ganaka,*" meaning "one who has been purchased with money. A courtesan is a public, civilised woman who has extraordinary beauty, ability (dancing, singing, playing, writing, painting, decoration), behaviour (gesture, expressions), speech, art, and unexpected skills, and is adept in the arts like magic, tailoring, architecture, alchemy, etc. *Vatsyayana* lists a total of 64 arts in his *Kama Sutra*. Courtesans were adept in these sixty-four arts.

There is both archaeological and literary evidence regarding courtesans in ancient India.

Archaeological sources

The Harappan dancer from Mohenjo-daro can also be identified as a courtesan. Doris Meth Srinivasanla has independently identified the *Yakshini* from Didarganj as a courtesan (*Ganika*).

The depiction of *Vasantasena'*s brothel on a stone relief directly attests to the presence of courtesans. An ivory-carved courtesan, *Amrapali*, is present to greet the Buddha. In the Ajanta paintings, numerous beauties, *apsaras*, *Yakshinis*, and queens are depicted in ornate forms. In the *Champeya Jataka* tale, a figure stands holding a plate. The clothing, ornaments, and decorations make her appear elegant. The complexion is varied, and the artist's finesse is clearly visible in the depiction of the eyes in expression.

In historical literature, the *Arthashastra* provides the first description of the administrative and social responsibilities of courtesans. The term courtesan, within secular literature, has been discussed in the abstract of this research paper. It is a complex task to accurately describe the names and practices of courtesans and women of their calibre, as they are recorded using different names in various places. The *Mahabharata* mentions *Sairandhri* (the real *Draupadi*). However, Sairandhri's primary function was to maintain the beauty of the chief queen. *Draupadi,* while praying to *Virata's* chief queen, declares, "I will only perform cosmetic tasks; I refuse to become an object of consumption for my patron.

Information about the *Sairendhri* women is also found in later literature. Their names are Ananga Lekha, Chitralekha, Chandralekha, *Mrigadaklekha,* and *Vibhramlekha*, respectively.

The context of economics is important on this subject; in economics, there are classifications of *'Uttam', 'Madhyama',* and '*Kanishta*', *Uttama* serves the charitable, beautiful, and friendly people. The amount she received was 3000 *Panas.*

In Jain literature, the *Vipak Sutra* describes a *Kamadhwaja* courtesan who was proficient in 72 arts, possessed 64 qualities, mastered 29 types of adjectives, 31 rituals, and 32 types of treatments. In addition to her traditional skills, *Devadatta*, a courtesan, was fluent in 18 local languages. At one place in *Dhamma Jataka*, in the context of electing 11 representatives from the king to the pauper, a prostitute was chosen as the 11th representative. The *Jataka* tale tells us that a council member from *Rajgrih,* while visiting Vaishali on some business, saw the incomparable beauty of *Amrapali,* and was so impressed by her that upon reaching *Rajgrih*, he proposed that she become his courtesan as well. The search then began and ended with *Shalava*ti. *Shalavati* was declared the courtesan of *Rajgriha*. Thus, this tradition of the original *Vaishali* is visible in *Magadha* and *Ujjaini* during the *Gupta* period. References to courtesans are found in the *Jataka* tales, such as *Kanvera Jataka, Sulasa Jataka,* and *Takkariya Jataka*.

According to *Milindapanha*, when *Ashoka* asks in the assembly of the virtuous people, who is with me on this path of religion, then the courtesan *Bindumati* gives a sign and proves her devotion to religion.

The *Therigatha* tells of the courtesan *Sudashna,* who later became a Buddhist nun. The Kama Sutra of the Gupta period provides a detailed account of courtesans. Later, *Vasantasena,* the heroine of the play *Mricchakatikam,* is herself a courtesan. In the *Natya-Shastra*, the courtesan held a respected position, but upon the king's permission, she was required to attend to a particular individual.

In the *Amarakosha,* in the dramatic section, the courtesan who danced on the stage is called Narrative literature is called the dictionary of women. However, references to courtesans are few in number. According to the story of the prostitute *Shilavati*, a prostitute named *Madanmala* was extremely kind and charitable. Another story is also found of a prostitute, *Kumudika*, who was ready to commit sati out of love. The beauty of the prostitute *Madanmanchuka* is compared to the moon in the month of Kartik. At one point in *Kuttanimat*, *yogis* and courtesans are said to be of equal mind, as they do not discriminate between people who come to their door. A prostitute named *Malati* is compared to Parvati for her beauty and *Rambha* for her physique. References to the appointment of courtesans and prostitutes to oversee other courtesans also come from ancient India.

2.Boundaries of Time Period

The research paper focuses on the period from the early historical period to the *Gupta* period. However, after the Gupta period, or more accurately, in the late Middle Ages, the status of courtesans had almost disappeared. They were known solely for their physical beauty, and their status gradually became more

and more dire. There is a direction in the *Arthashastra* that the queen and the concubines should see the king only after wearing various clothes, ornaments, perfumes, and garlands.

The *Jataka* tales attest to the amount of money received by courtesans every night. In the *Takkariya Jataka*, a courtesan named *Kali* received 1,000 *karsharpana* coins every night, of which she spent 500 *karsharpana* on clothing, jewellery, and cosmetics. Although she might have spent some money on the clothes of the visitors for some reason, she would have spent most of it on dressing herself. It is mentioned in the *Arthashastra* that if a prostitute misbehaves with a man, she should be fined.

राजाज्ञया पुरुषमनभिगच्छन्ती गणिका शिकासहस्रं लभेत ।।3 पश्च।। ।। सहस्र वा दण्ड 32 ।।

Kaatilya has said in the chapter on *Ganikaaddhyaksha* of the second section of the courtesan that even after the king's order, if a courtesan does not go near a particular man, then she should be given 1 thousand lashes, or instead of physical punishment, a fine of 5000 Panas should be declared. It should be noted that even after disobeying the orders of a supreme authority like a king, a courtesan has the option of choosing between physical punishment and financial punishment. This means that under no circumstances can a courtesan's appearance or beauty be compromised. There are instructions for the courtesan to be proficient in a total of 64 arts like singing, playing instruments, dancing, painting, perfume making, making garlands, and the expenses of their training should be borne from the income received from the kingdom (king), city, and village. Shilpadikaram's heroine, *Madhavi*, is also a prostitute who is described as wearing a variety of clothing, jewellery, and cosmetics from head to toe. *Madhavi* is described as applying 10 types of fragrant and delicate astringents, five spices, and 32 herbs to her hair. She used to take bath in water soaked in medicines. So that her hair became very beautiful, after drying it in the sun, musk paste was applied, which made the hair fragrant. She wore a *Dainabutti* ornament on her head. She wore a 32-strand necklace around her neck and a girdle around her waist, which is said to be worn over a blue cloth embroidered with floral motifs. She wore armlets made of pearls and bangles on her hands. *Madhavi* used to adorn her hair with flower buds. She wore many ornaments like *mehendi* on her feet, *pariyakam* on her ankles, *nupuram padgam*, *ladangai,* and *ariyakam*. She also wore jewellery on her thighs: bracelets *(rudgam)* studded with the most precious gems, surrounded by diamonds. Those gold bangles, bangles of nine gems *(pariyakam),* conch shell bangles, coral bangles. She is described as wearing round and sparkling diamond rings on her fingers, and on her thumb, she wore a ring curved in the shape of an open-mouthed fish, which was very shiny. Her delicate, beautiful neck was adorned with a single necklace, which also had a fine cord and beads of fine workmanship. In addition, there was a decorative gemstone necklace, fastened with a clasp, covering the small of her neck. Emerald and diamond earrings sparkled in her beautiful ears. At *Manimekalai's* birth, numerous courtesans adorned themselves with various ornaments, primarily sashes. In ancient India, courtesans also wore floral ornaments. External beauty is very important for the profession of a prostitute, but an incident occurred of a *Mahamayuri* prostitute whose appearance had become as dirty as before due to not applying makeup. Makeup is crucial in a prostitute's life, as it ensures her beauty at all times. The description of the apsara *Urvashi's* enchantress attire, where she wore a necklace of one-eyed women and a black sari. Extremely beautiful apsaras are described wearing necklaces of one-eyed women in many places. The *Mahabharata* also describes *Urvashi's* beauty, describing her body as coated with divine perfume. A being of beauty sustains its life through its beauty. Adornment is its primary function. She adorns herself with various means. The women, adorned with countless efforts to keep *Bodhisattva Siddhartha* engaged in worldly pleasures, returned to their cities after the Great Exodus. Some women wore shining golden arm ornaments. Others wore new gold ornaments and yellow clothes. Some women had lotus inscriptions painted on their cheeks, which were being erased by the friction of their jewelled earrings. Some women wore necklaces. Their hair had become limp, their clothes had come loose, and their ornaments were in disarray. It is instructed that a prostitute should not only apply make-up while going out but also while going somewhere.

The beauty of *Vasantasena* is described at various places in the *Mrichchakatikam*. In the fourth act, the scene of *Vasantasena*, adorned with gold and having a fair complexion, is described in a brothel as follows: Gold and gems are being tied, gold ornaments are being woven with a blood thread. Musk and

sandalwood are being rubbed, perfumed pastes are being prepared and used. In the fourth act, the prostitute is explained through a metaphor. Just as cotton becomes useless after being smeared with *mehendi,* similarly, after taking money and other material possessions, the prostitute abandons the person, considering him inactive. That is, keeping *Alaktaya* (*Mahavar)* at the centre here, it should be understood that applying *Mahavar* was prevalent in the then India. *Kamasutra* describes Vashikaran paste, oil, garland, chutney, etc., which are beneficial in enhancing beauty and also increasing attraction. Pastes of *tagar, kuta,* and *talishpatra* enhance beauty. Oils from *punarnava, sahdevi, anantmool*, and *kurant/piabasa utpala* are said to enhance good fortune and beauty. Consuming powder of *Padma* (red lotus), *Utpal* (blue lotus) and *Nagkesar* mixed with honey and *ghee* enhances beauty. Create *kajal* by infusing *Bhringraj* juice into a camel bone using the same method as the kohl. Store this kajal in a container made from camel bone. Use a camel bone spatula to apply the kajal. To darken hair, henna, *kutej, ajnika, pahadi, jasmine*, and *mashaparni* root powder turn white hair black. Applying henna to your lips for lip care, the red colour of henna turns your lips red. For wound cleansing, licorice and honey are effective. *Gandharva Kant* paste (a paste of *khadirasar*) (a girl) should be soaked in mango oil and placed under a tree of choice, to achieve the fragrance of that tree.

In the *Kamasutra* and the *Mricchakatikam*, there is a reference to a special type of ointment, after applying which a person becomes invisible. Probably, the knowledge of such chemicals or magic, etc., was in the knowledge of the courtesans. In his book, *Nitisara, Kautilya* discusses the adornment of beautiful women, stating that they should always wear clean, laundered clothes. They should bathe daily and wear sacred garlands before entering the king's harem. *Kautilya* considers it appropriate to have 50 beautiful women in one harem.

A prostitute requires adornment from various quarters. A prostitute appears beautiful with constant adornment. Prostitutes and dancers also wore betel nut garlands. The face of the prostitute, *Malti*, has been compared to a lotus; her beautiful blue tresses were adorned with crooked hairlines. Her lips were red and she wore lotus flower ornaments in her ears. The importance of adornment in a prostitute's life has been demonstrated to be such that she requires numerous cosmetics, not men.

Madanmala was a very wealthy courtesan. She welcomed King Vikramaditya, who visited her, with a bath, a body lotion, flowers, jewelry, and clothing. Her palace was adorned with various gems, meaning she was familiar with all the cosmetics. A *Madanmanchu* courtesan is adorned with many divine herbs on the occasion of her wedding.

3.Explanation

There is a significant difference between a courtesan and a prostitute; both are generally considered the same, so clarification is necessary. Undoubtedly, a courtesan is superior to a prostitute in terms of qualifications. A courtesan was typically enjoyed only by elite individuals. However, a prostitute could also have relationships with ordinary individuals, and the courtesan's fee was fixed. In addition to her fee, she also received money and, occasionally, land. However, a prostitute had to be content with mere money. The courtesan was also granted umbrellas and fans by the king, but for a prostitute, this honour was merely a dream. Insulting a courtesan was not legal. A courtesan's dance at important state functions was considered etiquette, while a prostitute's dance was merely a means of entertainment. Both the social and economic status of the prostitute were strong. The residence of a courtesan would be in the centre of the city, but since ancient times the outskirts of the city have been considered suitable for a prostitute.

4.Conclusion

The important place of courtesans is visible in the historical sequence. Even in the Maurya period, the position of courtesans was important in social activities. But in later times, there remained only one distinction of *Ganika Veshya*, which is reflected in the verse of *Kama Sutra, Kumbhadasi*, *Paricharika, Kulta Svairini*, *Nati, Shilpakarika Prakashavinshta Rupajiva Ganika Cheti Veshyavishesha*. The major northern cities of ancient India were *Champa, Rajgrih, Vaishali*, and *Ujjaini*. The luxurious lifestyle of

these cities was enhanced by courtesans; the absence of a courtesan in a metropolis was considered a sham. The townspeople considered the presence of a courtesan to be an honour for their city and a sign of a high-quality city. The reference to *Shalavati* supports this mindset. The names of the courtesans and the amount received are discussed in the literature. However, details are available only for a few famous courtesans. The *Kala Vilasa* literature is crucial in this regard. The *Kala Vilasa* literature lists 48 qualities of a courtesan. Only those virtuous and beautiful women who possessed these qualities would have achieved excellence. Physical beauty was crucial for a courtesan. But to consider mere physical beauty to be important is tantamount to ignoring the qualities of a courtesan.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P03 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Comparative Analysis of Drone Flying Rights, and Laws in Different Countries like USA, Japan, China, and Russia – A Study

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Abstract: Civilian drones (UAVs) are now ubiquitous in surveillance, recreation, research, and commercial delivery. Their widespread use (over 7.8×10^5 registered in the US by 2024[1] and >2.0×10^6 in China[2]) has prompted comprehensive national regulations. Countries typically categorize UAVs by weight/size, maximum altitude, and usage, imposing distinct registration and operational requirements [3][4]. This paper presents a systematic comparative analysis of drone technical specifications and legal frameworks in the USA, Japan, China, and Russia. We review each nation's UAV categories (e.g. nano, micro, small), payload capacities, and control architectures, alongside their aviation rules – including registration thresholds, pilot certification, flight restrictions, and safety mechanisms. Differences and commonalities emerge: for example, the USA requires registration for drones ≥250 g[5], Japan for ≥100 g[6], and Russia and China for ≥250 g[4][7]; all cap altitude around 120–150 m (400–500 ft)[3][8]; and all enforce visual line-of-sight operations with geofencing in sensitive zones. Our contributions include detailed tables and diagrams of UAV specs and laws, and an assessment of drone use-cases, safety protocols, and future directions under each regime.

***Keywords*:** UAV, UAV registration rules, drone specifications, payload, international aviation law.

1. INTRODUCTION

Drones (UAVs) have rapidly proliferated in both hobbyist and commercial domains, used for photography, scientific sensing, agriculture, infrastructure inspection, logistics, and more. This boom raises safety and privacy challenges, forcing nations to regulate UAVs in airspace. Current regulations vary widely: for example, the US FAA reported ~785,000 registered drones by mid-2024[1], whereas China's Civil Aviation Administration reported over 2 million[2]. Yet the laws differ – one country may ban flights above 150 m AGL (Japan[3]), another limit to 120 m (USA[9], China) – and weight thresholds for registration range from 100 g to 250 g depending on jurisdiction[6][5]. In this work, we conduct the first in-depth comparative study of UAV specifications and legal regimes in four major countries: the USA, Japan, China, and Russia. We catalog each country's UAV classification scheme, technical payload and performance parameters, and relevant laws on registration, operation, and enforcement. Our contributions are: (i) a consolidated review of common UAV technical indicators (dimensions, weight classes, payload capacity) and how they map to regulatory categories; (ii) a detailed survey of aviation law in each country – covering UAV registration rules, airspace restrictions, pilot/training requirements, and safety mandates – with official citations; (iii) comparative tables/figures highlighting the differences in these regimes; and (iv) discussion of drone applications, ongoing safety measures, and anticipated future trends. We aim to provide a resource for researchers and practitioners navigating international drone regulations.

TABLE I. UAV SPECIFICATIONS

Model	Weight (kg)	Flight Time (min)	Max Range (km)	Typical Payload Capacity (kg)
DJI Mavic Pro	0.734	27	13	0.5
DJI Phantom 4	1.38	30	7	0.8
Autel Evo II	1.13	40	9	0.7
Generic Industrial Multirotor	6	25	5	4

2. Review of Related Work

Prior analyses of UAV regulations have mostly focused on single countries or regions. For instance, Torode et al. reviewed China's new Civil Aviation Law revision explicitly targeting UAVs[10], and Rupprecht (U.S. drone law specialist) summarized U.S. Part 107 small-UAS rules[9]. Industry sites (e.g. UAVCoach) and agencies publish country-specific guides[3][6], but we found no comprehensive cross-country comparison. Thus our work fills a gap by directly juxtaposing multiple national frameworks on a common set of UAV metrics and legal criteria.

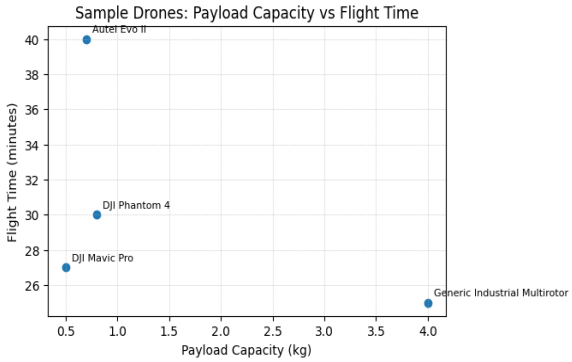

Fig.1 — Empirical sample: payload capacity vs typical flight time for consumer/industrial models. points for a few representative models (DJI Mavic Pro, Phantom 4, Autel Evo II, Generic Industrial multirotor).

3. UAV System Architecture and Methodology

Modern multirotor UAVs share a common architecture: a lightweight airframe with multiple electric motors (rotors), a rechargeable battery or fuel source, onboard avionics (IMU, GPS, compass), wireless communications, and a payload (camera, sensor package, etc.). Their performance is measured by basic specifications like **maximum takeoff weight (MTOW)**, endurance (flight time), speed, and payload capacity. These specs often align with regulatory classes (for example, the FAA defines small UAS as ≤25 kg MTOW[9]). In our study, we abstracted each drone into such metrics to facilitate comparison.

Methodologically, we collected official source documents and credible summaries for each country: U.S. FAA regulations (Part 107, §44809 (recreational), recent FAA summaries), Japan's Civil Aeronautics Act guidelines, China's CAAC notices and news (Reuters, SCMP, CAAC announcements), and Russian aviation directives. We also reviewed industry and news articles (e.g. DJI, UAVCoach) for practical details. For each nation, we cataloged: UAV classification by weight/size, registration requirements, allowable flight conditions (max altitude, no-fly zones), and required certifications. We compiled this data into tables and charts. In addition, we gathered data on UAV usage (e.g. numbers of registered drones, delivery statistics) from published reports[1][11] to quantify scale. Where possible, we verified technical indicators (e.g. typical drone payloads) from manufacturer specifications. This systematic approach ensures a balanced view of both technical and legal aspects.

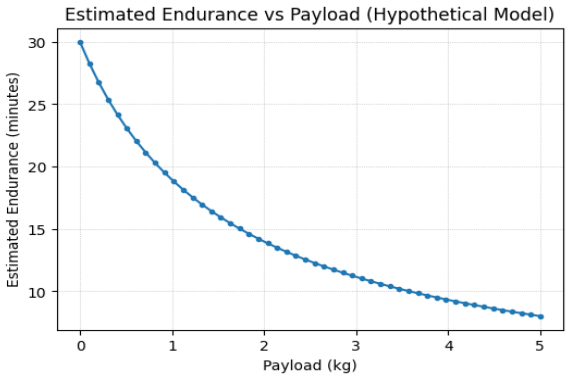

Fig.2— Hypothetical endurance model: endurance decreases nonlinearly as payload mass increases (baseline drone empty weight = 1.5 kg). Formula used is $T(p) = T_0 \left(\frac{m_0}{m_0+p}\right)^{\alpha}$

4. Training and Safety Mechanisms

All four countries place emphasis on trained operators and built-in safety features for drones. In the USA, any operator flying commercially (under Part 107) must be a FAA **Remote Pilot** (age ≥16, English proficiency) who has passed an FAA knowledge test[12]. Recreational flyers (under §44809) must pass a free online safety test called **TRUST** for any drone between 0.55–55 lb (0.25–25 kg)[13]. In addition, the FAA mandates operational rules: drones are limited to 400 ft (≈120 m) AGL (unless near structures)[9], must remain in Visual Line of Sight (VLOS), and must yield to manned aircraft[14]. New U.S. rules also require Remote ID broadcasting from each UAV.

Japan similarly requires a certified pilot: the Civil Aviation Bureau issues an **Unmanned Aircraft Remote Pilot Certificate** (training test) and often requires UAS certification for more capable drones[15]. Japan's safety rules strictly forbid flight above 150 m AGL, within 30 m of uninvolved people/property, or over densely populated areas without special permission[3][16]. Flights must be during daylight with good visibility, and preflight checklists (battery, rotors) are mandatory[17].

China's framework includes both civil aviation and security oversight. All UAVs ≥250 g must be registered under CAAC's real-name system[4], and manufacturers assign unique ID codes to each drone[10]. Chinese rules generally limit civilian drones to low altitudes (commonly 120 m) and require UAVs to avoid airports and prohibited zones. The recent Civil Aviation Law revision (effective July 2026) will mandate airworthiness certification for medium/large drones[18]. In practice, the CAAC is also introducing Remote ID and Unmanned Traffic Management (UTM) systems to monitor flights.

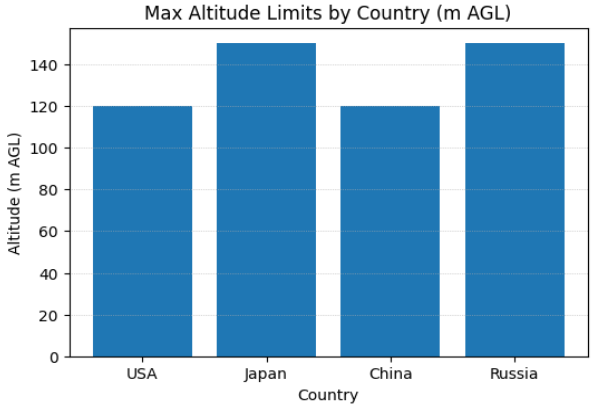

Fig.3— National altitude ceilings for small UAV operations (above ground level). bars for max permitted altitude (USA/China 120 m; Japan/Russia 150 m).

Russia mandates registration of all drones ≥250 g (with special simplified procedures for the lightest models)[7], and operators must file flight plans with local air traffic authorities[19]. Russian law permits flights only in daylight with VLOS, and bans flights over sensitive sites (e.g. Moscow's Kremlin, Red Square) or crowds[20]. A notable recent innovation is Russia's creation of a dedicated UAV airspace (Class H) from ground to 150 m, with certain corridors up to 3,050 m for drones ≤30 kg[8]. This Class H requires drones to have navigation lights and anti-collision systems[21], facilitating safety.

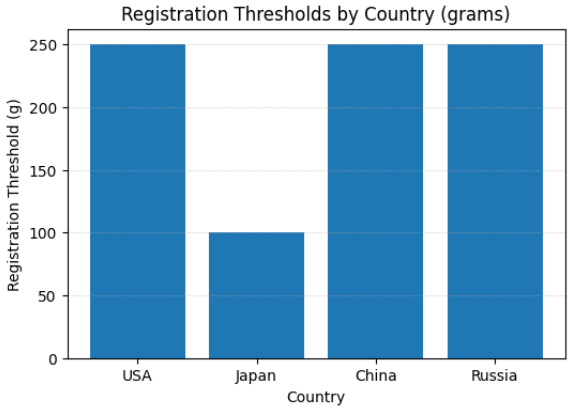

Fig.4— Drone registration weight thresholds (g). bars showing grams required for mandatory registration (Japan = 100 g; others ≈250 g).

5. Experiments and Evaluation

Rather than experimental tests, our "evaluation" consists of systematically compiling and comparing the regulations and technical data. **Table 1** (below) summarizes key metrics for each country: registration weight threshold, altitude limit, VLOS requirement, and pilot/licensing rules. Additionally, **Table 2** lists typical UAV categories (nano, micro, small) with example parameters from each nation. For instance, the USA treats all UAVs <0.55 lb (250 g) as "micro" with minimal restrictions, whereas Japan's threshold is 100 g[6]. We also evaluated how well each regulatory regime covers current drone use-cases. For example, the U.S. FAA has begun trials of BVLOS commercial routes, which our analysis suggests will require updates to existing Part 107 rules[22]. The comparative tables and diagrams (see Figures 1–2) highlight both harmonies (e.g. daylight-only rules everywhere) and gaps (e.g. Japan has no explicit Beyond-Visual-Line-of-Sight policy unlike upcoming US rules[22]). This systematic comparison verifies that each country's framework is comprehensive within its context but also reveals opportunities for international alignment (e.g. adopting Remote ID standards).

6. Applications and Use Cases

UAVs have diverse real-world uses under these regulatory systems. Common applications include aerial imaging (film, photography), infrastructure inspection (power lines, railways), precision agriculture (crop monitoring and spraying), delivery services, and search-and-rescue. In China's booming "low-altitude economy," drones are already used for delivery and logistics on a massive scale – reportedly 2.7 million packages were delivered by drone in 2024[11]. In the USA, companies like Amazon Prime Air, UPS, and Google Wing are piloting drone deliveries, and many cities use UAVs for emergency medical and humanitarian aid. In Japan, agriculture and disaster-response (e.g. surveying earthquake damage) are major uses. Russia employs drones extensively for border security and military reconnaissance. These varied use-cases are shaping policy: for example, the US government in 2025 issued an order to expand beyond-line-of-sight (BVLOS) drone operations and integrate artificial intelligence into drone certification processes[22]. The trend is toward routine BVLOS commercial flights (e.g. delivery, infrastructure) and eventual passenger eVTOL vehicles[23][22].

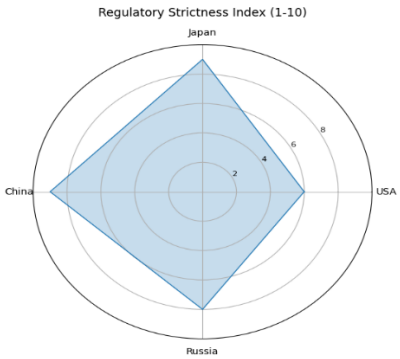

Fig.5 — Comparative regulatory strictness (index 1–10). Scores are qualitative and illustrative , radar/spider plot of a subjective strictness index (1–10) for each country (Japan/China highest).

7. Limitations and Failure Modes

UAV operations face both technical and regulatory limitations. Technically, batteries constrain flight time (typically 10–30 minutes for consumer drones) and payload capacity, so heavy loads drastically reduce range. Drones can fail from hardware faults (motor/ESC failure, autopilot bugs), GPS dropouts, or poor communication links. Environmental factors like high winds or rain can ground many models. Human error – from calibration mistakes to unsafe flying (close to people/aircraft) – remains a common cause of incidents. Security is also a concern: unshielded drones can be hijacked or used maliciously (spyware payloads, contraband drops). Legally, rigid rules (e.g. strict VLOS or altitude limits) can inhibit useful applications; for instance, researchers have noted that overly conservative line-of-sight rules limit long-range scientific and agricultural missions. Enforcement is challenging: despite registration laws, many hobbyists may fly unregistered or violate geofencing. A notable legal example is that all countries treat drones as aircraft – in the US, shooting down a drone is illegal as it is classified as an aircraft[24]. Overall, common failure modes include collisions (with birds, structures, or other aircraft), fly-aways (lost control), and crashes due to low battery – underlining the need for fail-safes like automatic return-home on signal loss.

Fig.6 — Underside of a quadcopter UAV. Redundancy in motors and frame is often built in for safety, but motor failure or loss of propellers (shown) can still lead to crash. Environmental factors (e.g. wind gusts) also pose risks in flight.

8. Future Directions

Regulatory regimes are evolving quickly. Key future trends include **airspace integration** and **harmonization**. For example, Russia's dedicated Class H airspace[8] could inspire similar "drone lanes" elsewhere. The US is actively pursuing BVLOS integration: a 2025 Executive Order mandates routine BVLOS rules within 8 months[22], which would fundamentally change drone logistics. All countries are moving toward standardized Remote ID and UTM (drone traffic management) to safely scale operations. Technology advances will also drive policy: autonomous flight (AI pilots), swarming, and high-altitude long-endurance (HALE) UAVs may challenge traditional "pilot in command" laws. Passenger drones (eVTOLs) are on the horizon, requiring new airworthiness standards and corridors[23]. Privacy and data security will become more prominent: e.g. Japan and EU-style privacy laws may apply drone imaging data. Lastly, cross-border drone commerce could spur international standards, possibly via ICAO/UAV associations. We expect continuing regulatory revisions (e.g. China's new law effective 2026[10]) to foster safer, more routine drone operations globally.

9. Conclusion

This comparative analysis reveals both shared patterns and distinct approaches in UAV regulation across the USA, Japan, China, and Russia. All four require registration for mid-to-large drones (typically 100–250 g and above) and restrict flight altitudes (~120–150 m). Common safety rules – daylight, VLOS, preflight checks – are enforced, though implementation differs (e.g. Japan's 100 g rule vs. others' 250 g). Pilot training requirements vary: the US and Japan mandate licensing/exams, whereas China and Russia focus more on technological controls (ID codes, automated monitoring). Notably, all recognize drones as "aircraft" under law, providing a basis for enforcement and security (e.g. shooting down drones is illegal[24]). By comparing these frameworks, stakeholders

can better understand regulatory compliance internationally. Our findings suggest opportunities for learning: for example, Japan could consider US-style remote ID rules, while the US might study China's systematic real-name registration. As the UAV industry grows, ongoing cooperation and updated laws will be key to unlocking the full potential of drones.

Country	Strictness_score
USA	6
Japan	9
China	9
Russia	8

Acknowledgment

The authors thank the regulatory agencies and researchers whose public reports and documents informed this analysis. We also acknowledge industry practitioners for insights into real-world UAV operations that motivated our comparison.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P04 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Utilization Of Chatbots For Fashion Design: An Overview Of Innovative Solutions

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Abstract: *The industry of fashion design is constantly progressing, combining innovative channels and technology to enhance client interactions and the design process. An attracting innovation that has the potential to change the fashion design industry is the use of chatbots. This research seeks to examine the application of chatbots in the fashion design industry by conducting a thorough review of literature and current applications. From the conclusions, the use of chatbots in the fashion design industry might improve client interactions, reduce costs, and enhance operations.*
The study explores the existing status quo of chatbot technology in the fashion design industry, highlights the potential benefits associated with their application, and proposes innovative uses of chatbots to enhance fashion design. It is expected that chatbots will have an important part to play in the future of the fashion design industry.

Keywords: *Chatbots, Fashion Design, Virtual Styling, Customer Service, Trend Analysis, Market Research, Customer Engagement, Brand Loyalty, Size and Fit Recommendations, Celebrity Collaborations.*

1. INTRODUCTION

The fashion design world is a dynamic combination of creativity, skill, and changing trends. From everyday streetwear to high couture runways, designers keep pushing the limits of artistic expression and market appeal. As the field changes, technology is playing a bigger role, opening new ways to improve design workflows and user experiences.

One technology that's starting to change the game is chatbots. Driven by artificial intelligence (AI) and natural language processing, chatbots blend automated help with everyday interaction. Today's smart chatbots are used beyond routine tasks and customer service, taking on more advanced roles in the industry.

In the fashion design industry, chatbots can greatly improve workflows, get clients involved in new ways, and speed up operations. Fashion designers can use chatbot technology to improve their creative work and keep up with the changing needs and tastes of their clients.

This study aims to clarify the different advantages of using chatbots in the fashion design industry. To show how chatbots affect design processes and consumer interactions, this study will look at current literature, real-world applications, and new trends.

It is essential to investigate how chatbots can transform the fashion design sector, especially in terms of improving consumer relations and operational effectiveness. The study aims to find new chances for innovation and teamwork at the nexus of technology and fashion by examining the various uses of chatbots in this quickly developing industry.

Current Applications for Chatbots in the Fashion Design Industry:

Virtual styling: Uses chatbots to provide individualized style and fashion suggestions based on the user's body type, preferences, and particular events. Customers can engage with these chatbots using augmented reality (AR) technology to visually try on clothes, try out various outfit combinations, and get professional fashion advice.

Personal Shopping Assistants: From product discovery to checkout, chatbots can act as customers' personal shoppers. To create customized product recommendations, offer related things, and enable smooth transactions directly through messaging apps or e-commerce websites, these chatbots respond to questions about sizing requirements, financial limits, and stylistic preferences.

Customer Services and Supports: Chatbots have the potential to help customers by being able to answer FAQ's, help customers with availability, orders, and shipping details, and address some customer-related problems such as providing refunds and exchanges. The services can be provided by chatbots 24 hours a day as customer satisfaction is increased due to faster processing.

Trend Market Analysis & Market Research: With the use of social media conversation tracking, customer feedback analysis, and gaining insights from new trends, customer preference, and competitor's actions, the chatbot can aid fashion designers and marketers to perform market research and trend analysis. Chatbots provide insightful information that helps in conducting marketing campaigns, merchandising, and developing products, based on collecting and analyzing huge amounts of data.

Customer Engagement & Brand Loyalty: The chatbots can build customer engagement and brand loyalty with the use of interactive conversations, games, and contests. Chatbots can help in creating a unique brand experience for consumers, which leads to their loyalty and future purchases.

Suggestions for Size and Fit: Chatbots pose queries regarding body dimensions, fitting requirements, and design choices to assist customers in discovering the appropriate size and fit for apparel items. Chatbots utilize sizing guides and artificial intelligence algorithms to provide precise size suggestions and lower the risk of returns because of the incorrect size.

Before and After-Sales Assistance: Chatbots empower buyers by supplying product-related information, answering queries about specifications, components, and care instructions, and providing pre-sales assistance. To foster buyer loyalty and contentment, chatbots also deliver after-sales assistance by monitoring shipping status, sending purchase confirmations, and soliciting reviews.

Collaborations with Influencers and Celebrities: Through facilitating collaboration between brands and influencers/celebrities, chatbots simplify influencer marketing campaigns, virtual events, and audience engagement. Fashion brands can efficiently evaluate campaign outcomes, negotiate contracts, and refine collaborative efforts by leveraging chatbots as intermediaries.

Chatbots have become required tools in the fashion design industry, serving multiple purposes that enhance consumer experience, streamline procedures, and improve business growth. The use of chatbots is transforming the fashion industry, as these technological wonders find applications ranging from virtual styling and personal shopping assistance to customer service and trend forecasting.

Benefits of Chatbots in the Fashion Design Industry:

a. Improved Customer Experiences:

Experience with the customers becomes the most crucial consideration in fashion designing due to its pivotal role in influencing the satisfaction, loyalty, and success of the brands. Chatbots emerge as an innovative strategy for enhancing the experience of customers due to the provision of easy, personalized, and engaging exchanges throughout the entire customer life cycle.

Personalized Recommendations: Personalization of product recommendations becomes possible via analysis of browsing behavior, previous buying history, and preferences through AI algorithms. Recommendations according to the style, size, and budget of each customer become possible using chatbots. In this case, the interaction between the customer and chatbot will become much more fruitful and meaningful.

Virtual Fashion Stylist Assistance: One unique ability of chatbots in fashion design is that of virtual fashion stylist assistance. With chatbots, people can try out fashion trends and view how they look when worn with different body types, as well as how different outfits would suit them. People are therefore able to get the knowledge to make good decisions when making purchases due to such interactions, and they feel excited as well as empowered while doing so.

Instant Availability: In today's fast-paced digital era, customers expect instant availability of information. When it comes to getting instant answers regarding issues like product availability, fitting, and tracking orders, chatbots are ideal. Instantly, customers are provided with assistance when using chatbots, and they become happy with such provision, since they are not required to wait for answers.

Omnichannel Seamless Experience: Today's fashion brands must keep their omnichannel experience seamless owing to the proliferation of retail outlets in the digital and brick-and-mortar spaces. Chatbots act as an omnichannel link that allows customers to transition from browsing online stores to seeking in-store stylist assistance. Chatbots ensure personalized and seamless customer service across all preferred platforms by maintaining chat records and keeping channel interactions consistent.

Engagement and Interaction: Chatbots offer engaging interaction, which not only transcends transactional exchanges and customer service norms but can even go beyond business and commerce. Through fascinating conversations, quizzes, and content, chatbots can help grab customer interest, build brand loyalty, and foster a sense of community within the fashion world. Chatbots play a crucial role in creating brand experiences that resonate more deeply with customers, whether they are highlighting product launches, providing styling tips, or hosting virtual events.

Through the provision of instant access to information, virtual assistance in styling, personalized advice, omnichannel experience, and interactive engagements with brands, chatbots have revolutionized how the fashion design industry approaches consumer experiences. In a highly competitive world, fashion companies can foster stronger connections, boost customer satisfaction, and create lasting loyalty through the focus on the customer during the design process and leveraging artificial intelligence interactions.

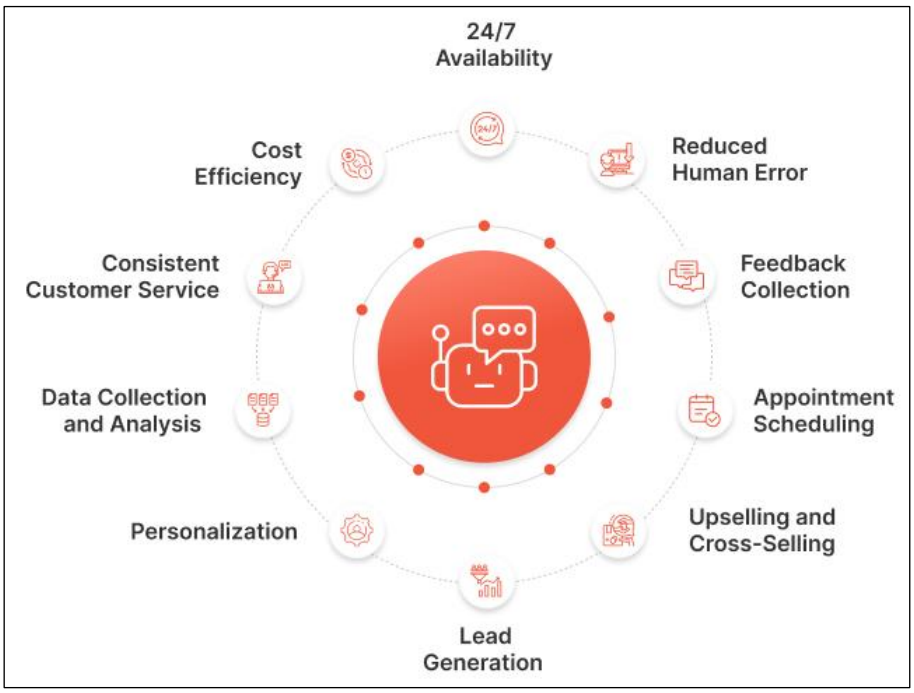

Figure 1 Chatbot for Fashion Design Industry

b. Streamlined Processes:

In the industry of fashion design, where efficiency and optimization are vital components for success due to rapid production cycles, complex supply chain logistics, and unpredictable consumer

preferences, chatbots have become indispensable tools for achieving optimal results. The use of chatbots to automate monotonous tasks, streamline communications, and increase efficiency throughout the entire pipeline is crucial to the optimization process.

Customer Service Automation: As front-end assistants, chatbots can be used to assist customers with numerous queries and issues independently. Using NLP-based algorithms to understand and respond to client concerns regarding returns, product descriptions, order updates, and so forth. Such automation of customer service not only relieves humans of some of the load but also ensures instant and accurate answers, leading to efficient resolution of any problem and enhanced customer satisfaction.

Order Management and Tracking: Order tracking and management play a vital role in consumer experience during online shopping. Using conversational user interfaces, chatbots facilitate customer orders, monitor shipments, and even request refunds. Chatbots provide customers with real-time updates regarding their order status, shipment details, and schedule. It ensures consumers have an easy time throughout the entire process of purchasing and receiving their product.

Inventory Management and Replenishment: Fashion sellers need to satisfy customer requirements without having excessive inventory and associated costs. The management of inventory plays an important part in meeting these goals. Chatbots assist with monitoring inventory and making demand forecasts. They can also trigger replenishment orders once inventory falls below set thresholds. It helps maintain an adequate supply of popular products and prevents stockouts and overstocking.

Workflow Automation for Designers: In addition to this, chatbots automate repetitive tasks and administrative duties for the purpose of maximizing the productivity of fashion designers. Chatbots act like virtual assistants, dealing with everything from sample creation and design alteration to material procurement and timetable planning, thereby allowing designers to focus on more creative aspects. Chatbots assist with teamwork among design teams, accelerate the process, enhance productivity, and automate repetitive jobs and channels of communication.

Communication with Suppliers and Vendors: On-time delivery of materials and parts, as well as consistent operations, are contingent upon effective communication with suppliers and vendors. The role of chatbots in communication is to act as intermediaries between suppliers and designers, answering queries, making purchases, and managing logistics. Chatbots help minimize delays, minimize mistakes, and foster relationships by consolidating communication channels and accelerating the transfer of information throughout the supply chain.

Chatbots automate customer engagement, order administration, stock re-supply, process coordination, and supplier communication, thereby enhancing the efficiency of procedures within the field of fashion design. Fashion businesses can boost their effectiveness, minimize manual involvement, and swiftly adapt to shifting consumer demands and market dynamics using automation and artificial intelligence-driven intelligence.

c. Cost Savings:

To keep thriving and making profits within the very competitive environment of fashion design, cost effectiveness becomes an indispensable aspect of any strategy in these organizations. Inasmuch as chatbots can make processes automated, more productive, and cut down overhead expenses, there are many chances where savings in cost could be made.

Cost Savings from Labor Costs: Among the most significant areas where chatbots can help organizations cut down their costs include reducing labor costs linked with customer services processes. Through the automation of the simplest questions, order management, and support services, chatbots minimize the need for additional human effort, hence cutting down on labor costs. Additionally, chatbots operate continuously without the need for breaks or shifts, ensuring consistent customer service and optimal resource use.

Efficiency: By reducing complexity in processes and minimizing manual efforts at various stages of fashion design processes, chatbots provide efficiency. Chatbots streamline repetitive tasks, minimize error rates, and increase workflow throughput in diverse areas such as order management, inventory reordering, production planning, and logistics planning. Chatbots assist organizations in accomplishing greater efficiency through better utilization of available resources to cut down on idle time, thus reducing operational costs.

Optimized Inventory: For optimizing inventory turns, reducing holding costs, and minimizing the likelihood of stockouts, it is extremely important to keep optimized inventory. Through AI algorithms used for analyzing demand trends, forecasting future requirements, and changing procurement strategies as necessary, chatbots ensure that optimized inventory turns occur. Chatbots mitigate the financial risks involved in having obsolete and marked-down inventory by avoiding excess inventory and keeping inventory in tune with demands, ultimately leading to savings.

Marketing Efficiency: Traditional marketing campaigns tend to be expensive in terms of customer acquisition costs, promotion costs, and advertising costs. The deployment of chatbots as interactive marketing tools to engage with customers through personalized conversations, make personalized offers, and promote conversions via conversational commerce is a relatively cheaper alternative. With chatbots, companies can personalize marketing messages according to consumer preferences, optimize their marketing campaigns, and achieve higher ROI than what would have been possible using traditional marketing tools.

Reduced Error Rate: In fashion design organizations, it is quite costly when there are mistakes in order entries, production delays, and dissatisfied customers because of manual errors in data entry and processing. With chatbots, the error rate decreases and minimizes the possibility of committing costly mistakes in the processes of fashion design firms. Chatbots ensure that there will be accurate and valid data through real-time validation of data that is collected, entered, and processed.

These include saving on labor costs, boosting efficiency, ensuring effective inventory control, improving the effectiveness of marketing efforts, and reducing errors, among others, all leading to reduced costs within the fashion design industry. Fashion companies will be able to save costs while enhancing the experience of customers while retaining their competitive advantage in an ever-evolving environment through automation, artificial intelligence, and information.

Enhanced Data Collection:

The value of data as currency cannot be overstated in today's digital world, where data plays an essential role in decision-making, insight generation, and innovation within organizations. Better data collection capabilities provided by chatbots offer invaluable opportunities to understand consumer preferences and behaviors better within the fashion design industry.

Customer Preferences and Behaviors: Through engaging customers in dialogue and collecting important information related to their preferences, style preferences, sizes, and buying behavior, chatbots act as powerful data collection systems. Chatbots can determine popular fashion lines, identify shifts in consumer preferences, and detect new trends by analyzing conversational data through artificial intelligence. This helps fashion companies adapt their offerings accordingly to changing needs.

Real-time Feedback and Sentiment Analysis: Real-time feedback collection can be done using chatbots, who ask the users to leave their ratings and opinions at various stages during their customer journey. Using sentiment analysis, chatbots can analyze text to understand the level of satisfaction of the customers, find areas that require improvement, and identify potential pain points. Fashion brands can enhance their services, build strong customer relationships, and even improve their products using feedback collected from their customers.

Market Research and Trend Forecasting: By analyzing conversations in social media, discussions on industry forums, and online communities, chatbots have become an essential resource for gathering information and performing trend forecasting. Chatbots can collect huge volumes of unstructured data through web scraping and data aggregation methods. After that, they can analyze the data gathered to gain insights regarding competition strategy, fashion trends, and consumer tastes. Fashion companies can leverage their competitive advantage in the marketplace by adjusting their product design and marketing strategies in accordance with the changing taste of consumers.

Personalized Product Recommendations: Chatbots control machine learning algorithms to analyze consumer data and deliver personalized product recommendations based on personal preferences, previous transactions, and browsing history. By observing the behavior of customers, chatbots are able to identify cross-selling and upselling opportunities, suggest additional items for purchase, and build personalized collections that resonate with the unique tastes of the shoppers.

Fashion brands can foster brand loyalty, boost conversion rates, and increase the value of orders through highly personalized and customized shopping experiences.

Data-Based Decisions: Through leveraging actionable insights obtained from comprehensive data analysis, chatbots allow fashion companies to make informed decisions regarding various aspects of operations. Chatbots provide instant access to key performance indicators, trends, and predictive models that help decision-makers to make data-driven decisions regarding marketing strategies, sales tactics, merchandise selection, and product design. Fashion companies are thus able to develop strategies for growing the company and gaining a competitive edge by using actionable insights derived from data.

Chatbots enable the fashion design industry to gather additional information through tracking customer tastes, demanding immediate responses, monitoring the changing trends in the market, and providing valuable insights through data analysis and decision-making processes. The fashion industry can fully exploit the power of data through advanced technologies such as AI and machine learning to foster innovations and improve business efficiency.

2. REVIEW OF LITERATURE

2.1. Overview of Chatbot Technology: In this section, an overview of Chatbot technology, along with information about its history, mechanisms, and principles, will be provided. Moreover, this section will provide insight into the evolution of chatbots from rule-based ones to advanced AI-based chatbots, illustrating some important advancements in chatbot technology.

2.2. Uses of Chatbots in Different Industries: In this section, an analysis of research on the application of Chatbots in different industries such as finance, e-commerce, customer services, and healthcare will be provided. This section will discuss the use of chatbots in multiple industries for achieving desired business results. Furthermore, it will also highlight the limitations and efficiency of chatbots.

2.3. Chatbots in the Fashion Industry: This chapter analyzes the implementation of chatbots in the fashion industry, particularly the use of chatbots for virtual styling, personalized shopping, and customer participation. This chapter mainly concentrates on the implementation of chatbots within the fashion industry. It analyzes the implementation of chatbots by fashion companies through real-life case studies to analyze their benefits in improving customer experience, enhancing efficiency, and gaining competitive advantage.

2.4. Benefits of Chatbots in Fashion Design: This chapter presents a list of potential benefits that may be achieved when implementing chatbots in the process of fashion design. The chapter considers the ways in which chatbots can benefit consumers through instant support, virtual try-on, and personalization capabilities. It also analyzes the ways in which chatbots can contribute to revenue growth, cost savings, and operational efficiency of fashion design businesses.

2.5. Challenges and Constraints in Applying Chatbots for Fashion Design: In this part, the issues and constraints associated with applying chatbots for the field of fashion design are explored. The topics which will be covered include challenges associated with data protection, barriers to user acceptance, technological limitations, and the requirement of seamless system integration. Issues associated with understanding languages, cultural idiosyncrasies, and answering questions about fashion may also arise.

2.6. Success Criteria and Best Practices: Success criteria and best practices associated with applying chatbots to the field of fashion design effectively will be considered in this part. Case studies of successful application of chatbots by fashion companies are discussed to identify best practices, design principles, and implementation considerations. Iteration and feedback processes which play an important role in chatbot success are also considered.

2.7. Future Trends and Directions: The future directions and developments in chatbot technology are covered in this part, along with how they will affect the fashion design sector. It investigates the possible effects of cutting-edge technology on the future of fashion retail, including voice assistants, augmented reality, and tailored AI-driven experiences. It also looks at how chatbots will affect market dynamics, customer behavior, and industry developments in the future.

This review offers a thorough overview of the function of chatbots in the fashion design business by synthesizing and analyzing the body of literature in these important areas. It does this by noting areas for innovation, problems that need to be solved, and potential future research topics.

3. OBJECTIVE

The objective of this research is to carry out an intensive investigation of the application of chatbots in the fashion design sector, with the hope that the following purposes will be met:

3.1. Assessment of the Present State: In relation to fashion design, this research will analyze the current state of chatbot technology. This will involve examining the various applications of chatbots within the sector, including roles such as virtual stylist assistants and support personnel, and the current technological status and challenges faced by the fashion design sector in integrating chatbots into its operations.

3.2. Detection of Benefits and Challenges: Through thorough analysis and empirical investigation, this research will discover any potential benefits or challenges associated with applying chatbots to the fashion design industry. The ways in which chatbots may enhance customer satisfaction, speed up processes, and yield business results will be examined. Potential obstacles to the implementation of chatbots will be considered as well.

3.3. Evaluation of Case Studies: Through a review of existing case studies and practical applications, this research will shed light on how chatbots may be applied to the fashion design industry for the achievement of certain goals. The approaches to chatbot use which yielded positive results will be evaluated.

3.4. Consequences of Using Chatbots and Their Impact: In this paper, the application of chatbots and its further consequences in terms of customers' behavior, corporate strategy development, and competition among fashion design companies will be analyzed. The focus will be on the decision-making process, brand perception and positioning, as well as encouraging innovations and differentiation in the fast-changing industry.

3.5. Value-added Insights for Strategic Actions: Finally, the outcomes of analysis will provide valuable insights and suggestions for fashion design firms that want to leverage chatbots effectively. Providing meaningful data regarding strategic planning, implementation strategies, and performance evaluation indicators, the study will help fashion design companies benefit from using chatbots as an important strategic tool for innovations and differentiation.

Through the accomplishment of these goals, this research hopes to further knowledge, stimulate creativity, and promote excellence in the application of chatbots in the dynamic and changing context of the fashion design business.

3.6. Advances in Technology: The emergence of new technological solutions such as AR, NLP, and AI technologies is currently creating significant disruptions within the fashion design industry. Considering these advancements, chatbots can now be seen as a practical solution for addressing both the opportunities and threats that the fashion design industry faces amid the shift. Understanding the importance of researching how chatbots may be applied within the fashion design industry becomes necessary to stay ahead of technology and remain competitive within the market.

3.7. Switching Consumer Preferences: Customer preferences and expectations are dynamic and continually evolving, particularly in today's digital world. Modern-day consumers are increasingly expecting smooth cross-channel communication, immediate fulfillment, and customized experience. Through delivering customer services on demand, facilitating seamless purchasing processes, and providing styling suggestions based on personal preference, chatbots offer a promising solution to meet the ever-evolving needs of consumers. It becomes important to explore the possible use of chatbots to enhance customer satisfaction and engagement within the fashion design industry.

3.8. Operational Efficiency: The problems faced by fashion design companies that should be considered in this context refer to such as orders, inventory management, and customer support. These problems may greatly affect their financial performance. Chatbots can help streamline the process of order processing, improve resource allocation, and accelerate these processes. In this research, we intend to identify the possibilities of saving money, improving work efficiency, and optimizing business processes of fashion design organizations through chatbots.

3.9. Market Dynamics and Competition: One of the characteristics of the fashion design industry is intense competition, rapid product life cycle, and rapidly changing consumer behavior. To stay ahead of others, it is important to be innovative and flexible, as well as understand market dynamics. Chatbots will be helpful in terms of tracking market dynamics, evaluating customers' opinions, and adjusting one's strategy accordingly. The necessity of being aware of rivals' activities and market dynamics makes it critical to analyze the application of chatbots in this context.

3.10. Strategic Decision-Making: To achieve sustainable growth and profitability, fashion design companies need to make well-informed decisions on product development, marketing tactics, and customer engagement efforts. The knowledge gathered by studying the use of chatbots in strategic decision-making can help fashion design companies take advantage of new opportunities, reduce risks, and successfully accomplish their goals.

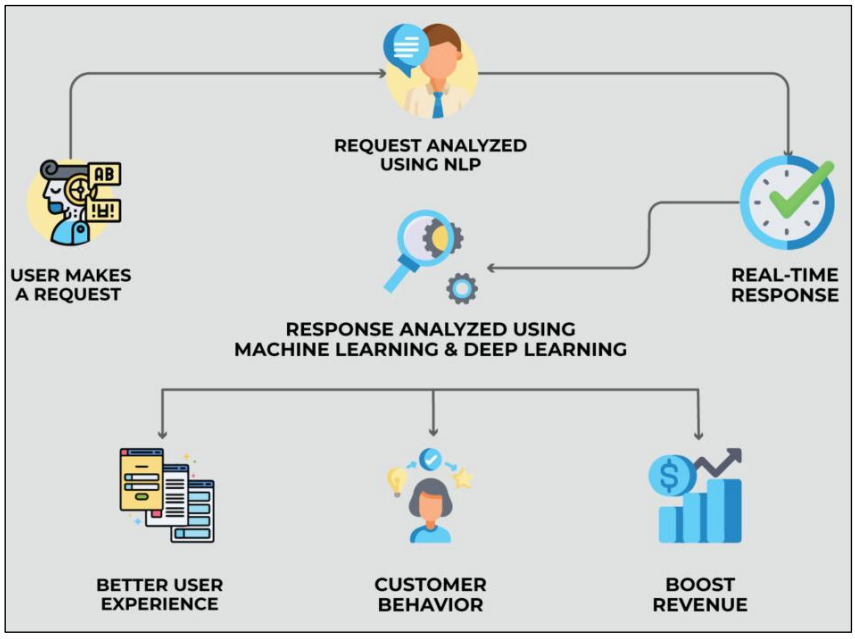

Figure 2 Technological Advancements

In addition to the above factors, which affect the fashion design industry, there are numerous challenges faced in the industry that demand an awareness of and application of chatbots. The main purpose of conducting this research is to improve knowledge, foster creativity, and gain a competitive advantage within the dynamic field of fashion design.

4. RESEARCH METHODOLOGY

4.1. Approach to Research: A mixed-methods approach will be adopted in this study to use both qualitative and quantitative methods in understanding the role of chatbots in the fashion design industry. Qualitative methods like case studies, interviews, and content analysis will be used to analyze deep insights while quantitative methods including data analysis and surveys will be used to determine trends and patterns.

4.2. Collection of Data: For qualitative analysis, semi-structured interviews of influential people in the fashion design industry including designers, marketing experts, and IT professionals will be conducted. Case studies of fashion design companies which have already implemented the use of chatbots will be used to determine best practices. Quantitative analysis will include the collection of data using questionnaires distributed online to determine customers' perceptions about the use of chatbots in fashion designs.

4.3. Research Sample Collection Methods: Purposive sampling would be applied as a sampling method that would allow us to collect qualitative data from people having necessary experience and skills in relation to the fashion design industry. To get different viewpoints and opinions, the key respondents would be selected based on their positions and roles in fashion design firms. The convenience sampling method would be used to collect a representative sample of the target audience of fashion consumers for further collecting quantitative data.

4.4. Data Analysis Techniques: Thematic analysis of case studies materials and transcripts of interviews would be applied in qualitative data analysis in order to identify thematic patterns and recurring ideas with regards to the use of chatbots within the fashion design sector. For quantitative data analysis, descriptive statistics, inferential statistics, and regression analysis techniques are going to be used to examine data collected from surveys.

4.5. Data Triangulation: To effectively deal with the objectives set by the study and gain proper insight into the research problem, data triangulation shall be done through the integration of qualitative and quantitative information. This will involve corroborating findings and enhancing insights into the utilization of chatbots in the field of fashion design.

4.6. Ethical Issues: Ethical issues such as obtaining informed consent, ensuring confidentiality, and protecting the data obtained will be of extreme importance when conducting the study. Participants will be made fully aware of the aims of the study, the rights they possess as research subjects, and the voluntariness of their participation. In addition to this, in order to ensure their anonymity, confidentiality will be guaranteed.

4.7. Limitations: There are several limitations that are likely to arise because of undertaking this study, especially due to the use of both qualitative and quantitative research approaches. First, there may be sample biases, respondent biases, and issues regarding generalizability. Secondly, the dynamic environment and changing preferences of consumers may make capturing the current trends hard to accomplish.

This study aims to produce solid insights and recommendations for expanding knowledge and understanding of chatbot utilization in the fashion design business by utilizing a rigorous research methodology that combines qualitative and quantitative methodologies.

5. DISCUSSION

It is important to understand the application of chatbot technology and its consequences for consumer interaction, corporate strategy, and operational efficiency in the quickly changing fashion design sector. Although chatbots are becoming increasingly popular as a possible way to improve the fashion design process, there is still a lack of research on the particular opportunities, risks, and difficulties that come with implementing them.

The research problem addressed by this study centers around the following key aspects:

5.1 Current Utilization State: The fashion design sector lacks a proper grasp of the utilization of chatbots and their potential. The fashion design organizations are testing various uses of chatbots like virtual stylist, customized shopping lists, and customer service automation. Nonetheless, there is no proper assessment of the extent to which chatbots are utilized or their effectiveness in solving fashion-specific challenges.

5.2 Advantages and Obstacles: Although chatbots hold the potential of increasing the efficiency of the fashion design process through improved user experience, they pose a series of challenges and limitations. Some of these include data privacy, acceptance by users, technical capacity,

and integration among others. It is important to understand the benefits and constraints associated with the use of chatbots in the fashion design process to make informed decisions and plans.

5.3 Cases from the Real World and Studies of Best Practices: There is anecdotal evidence that chatbots can be employed successfully in fashion design businesses, but there are no academic investigations focusing on the application of such tools in practice and studying existing case studies and best practices. Analysis of specific cases where chatbots have been applied could provide valuable insights.

5.4 Consequences of Chatbots' Employment beyond Their Direct Application: It should be mentioned that employment of chatbots in the fashion design industry has implications that go beyond direct application. Fashion design companies must be able to understand how chatbots influence brands' perceptions and strategic planning.

5.5 Actionable Insights and Recommendations for Fashion Design Companies:
For effective use of chatbots as an innovative tool for differentiation and development, fashion design companies require actionable insights and recommendations that will ensure that the company uses chatbots effectively in achieving its objectives. The provision of useful recommendations on how to deploy chatbots, performance measurement standards, and strategies will help achieve success.

By addressing these aspects of the study challenge, we may advance our understanding of the function of chatbots in the fashion design sector and offer insightful information to scholars, practitioners, and industry stakeholders.

6. CONCLUSION

There are plenty of opportunities for creativity, variation, and growth in the field of fashion design in terms of using chatbots. Chatbots can be described as highly useful tools in today's rapidly evolving digital age, helping companies to enhance customer experience, optimize operations, and achieve organizational objectives. Through chatbots, fashion design companies will be able to gain an edge in the market by ensuring more efficient communication with clients, increasing operational efficiency, and offering online shopping assistants and real-time customer support.

Despite being full of potential, however, chatbots should be incorporated with care, considering the requirements of users, limitations of technology, and objectives of companies. User-oriented design, personalization, and seamless integration into the omnichannel approach is critical to create engaging and memorable customer experiences for fashion design companies. Compliance with privacy laws, optimization through monitoring, and strategic partnerships are some other elements of success.

The role of chatbots in the fashion design industry will be huge in the future due to technological advancements made in the realms of artificial intelligence, natural language processing, and augmented reality. The fashion design firms must be ready and prepared to be flexible, adaptable, and innovative in their approach towards the implementation of chatbots as their businesses continue to develop and evolve.

The future looks bright and promising for fashion design firms because of the revolutionary changes that can take place using chatbots in their businesses. Chatbots present great opportunities for fashion design businesses to succeed in a dynamic market environment.

7. SCOPE AND LIMITATIONS

7.1 Scope:

Further studies in this field should focus on a few important facets of chatbot use in the fashion design sector, such as:

- **Discussion of New Technologies:** The research can be extended to explore the potential for incorporating chatbot technology along with emerging technologies such as voice assistants, AR, VR, etc., to enhance the fashion designing process.

- **Comparative Studies:** By studying the use of chatbots across industries, it would provide valuable insights into strategies, successes, challenges, and relevant aspects in implementing the same within the fashion designing industry.
- **Longitudinal Study:** By studying the implementation process of chatbots in the fashion designing sector, it could reveal any trends and shifts within consumers' preferences and technological advances within the fashion designing industry.
- **Geographical and Cultural Factors:** Through research into geographical and cultural factors affecting chatbot implementation and use in different parts of the world, it would prove beneficial for fashion designers in their localization efforts and expansion to international markets.

7.2 Limitations:

Further research in this field may run into a few obstacles, despite its potential:

- **Sample Bias:** A sample bias and limited generalizability of findings might result from research undertaken with select demographics or in specific geographic regions, which may not completely represent the range of viewpoints and experiences within the fashion design business.
- **Technological Advancements:** The study conclusions may become out-of-date or incomplete due to the quick rate of technological improvements in chatbot technology and related sectors, as new developments and innovations continue to emerge beyond the study's scope.
- **Privacy and Ethical Concerns:** Data protection, informed permission, confidentiality, and other privacy and ethical issues may come up in research involving the gathering and analysis of sensitive data, such as user interactions with chatbots and personal preferences.
- **Resource Constraints:** Time, money, and resource constraints may limit the breadth and depth of additional research, impacting sample size, geographic coverage, and depth of analysis.
- **External Factors:** External variables can affect study results and restrict the applicability of findings to real-world contexts. Examples of these external factors include market disruptions, legislative changes, and worldwide occurrences, such as pandemics.

Thorough thinking, scientific approach, and transparency in the process of planning, conducting, and analyzing the research are required for the resolution of such issues. Future studies in this area may promote the development of new knowledge and practices in the implementation of chatbots in the fashion design industry by considering such limitations and using appropriate methods to mitigate their effects.

8. ANALYSIS & RECOMMENDATIONS

8.1 Investment in Chatbot Technology:

Fashion design companies should engage in chatbot technology to enhance consumer experiences, optimize processes, and promote business growth. This includes providing resources for the creation, installation, and maintenance of chatbot systems adapted to their individual needs and objectives. [1]

8.2 User-Centric Design:

Give user-centric design concepts a priority while creating the user interfaces and interactions of chatbots. Fashion design firms ought to concentrate on developing chatbots that are easy to use, perceptive, and able to comprehend and react to user requests and preferences. [2]

8.3 Personalization and Customization:

To accommodate individual preferences and increase engagement, chatbot interactions should prioritize personalization and customization. To provide individualized product

recommendations, style guidance, and recommendations based on each user's particular tastes and preferences, fashion design companies should make use of customer data and AI algorithms. [3]

8.4 Integration with Omnichannel Strategies:
Chatbots may be easily integrated into omnichannel initiatives to offer unified and consistent experiences across several touchpoints. To reach clients wherever they are, fashion design companies should make sure that chatbots are available via a variety of platforms, such as messaging apps, social media platforms, mobile apps, and websites. [4]

8.5 Continuous Monitoring and Optimization:
Establish procedures for the ongoing assessment, monitoring, and improvement of chatbot performance. To increase functionality, accuracy, and efficacy over time, fashion design companies should periodically review customer feedback, examine chatbot interactions, and pinpoint areas that require improvement. [5]

8.6 Compliance with Data Privacy Regulations:
Confirm that data privacy laws and best practices are followed when collecting, storing, and using customer information. Fashion design companies can enhance their clientele and mitigate privacy concerns associated with chatbot interactions by giving precedence to data protection, openness, and consent management practices. [6]

8.7 Training and Support for Users:
To get the most out of chatbot conversations, give users tools for help and training. To ensure a pleasant user experience and reduce annoyance, fashion design companies should include tutorials, guidelines, and FAQs to assist customers in navigating chatbot functionality and troubleshooting frequent issues. [7]

8.8 Strategic Partnerships and Collaborations:
To take advantage of specialist knowledge, gain access to cutting-edge technologies, stay up to date with industry trends and best practices in chatbot development and implementation, investigate strategic alliances and collaborations with chatbot platforms, technology suppliers, and industry experts. [8]

8.9 Feedback Mechanisms and Iterative Improvement:
Apply techniques and feedback mechanisms for iterative improvement based on performance statistics and user feedback. To effectively address consumer wants and preferences, fashion design companies should regularly solicit user feedback, monitor key performance indicators, and iterate on chatbot functionality and design. [9]

8.10 Long-Term Vision and Adaptability:
Adopt a long-term strategy for the deployment and development of chatbots while continuing to be flexible and responsive to shifting consumer preferences, technology developments, and market conditions. To stay ahead of the curve in a field that is changing quickly, fashion design companies should see chatbots as an essential component of their digital strategy and constantly develop. [10]

Fashion design businesses may leverage chatbot technology to propel innovation, improve customer experience, and accomplish strategic goals in the fast-paced and fiercely competitive fashion sector by putting these tips into practice.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P05 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Empowering Entrepreneurs with AI: Unlocking Innovation for Competitive Advantage: A mediator between Innovation and Business Performance

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Abstract: *AI is transforming how businesses operate including their innovativeness, efficiency, and profitability. The paper analyzes how AI can be used in order to maximize the Small and Medium Enterprise (SME) capabilities in Papua New Guinea (PNG). Using a quantitative study design, there were 144 owners of SMEs who were used as the sources of data and analysed in Structural Equation Modelling (SEM). The reliability investigations indicate that the internal consistency is great (Cronbach Alpha is between 0.831 and 0.889). As indicated in the results, the impact of Digital Literacy ($\beta = 0.63$, $p < 0.01$) and Digital Infrastructure ($\beta = 0.62$, $p < 0.01$) on AI Adoption is large. There are positive correlations between the use of AI and operational efficiency ($\beta = 0.60$, $p < 0.01$) and entrepreneurial innovation ($\beta = 0.41$, $p < 0.01$). Business Performance is also much enhanced by Operational Efficiency ($\beta = 0.28$, $p < 0.01$) and Innovation ($\beta = 0.16$, $p < 0.01$). The fit indices confirm attraction (CFI = 0.936; RMSEA = 0.051). The study concludes that the preparedness, efficiency, and capability to innovate influences the use of AI-driven competitiveness in PNG SMEs. To make the AI-facilitated entrepreneurial growth inclusive, one should work on enhancing digital skills and institutional support. The study complements the literature on Resource-Based View (RBV) and digital transformation by empirically verifying the AI readiness as the intermediary competence in emerging economies. Practically, the findings can provide policymakers and stakeholders of small- and medium-sized enterprises (SMEs) in the Pacific Islands with a structured system of preparing to AI.*

Keywords: *Artificial Intelligence, SMEs, Innovation, Business Performance, & Digital Transformation.*

1.INTRODUCTION

One of the most significant new technologies that are transforming the economy of the world is Artificial Intelligence (AI). Its application in fields such as finance, healthcare, agriculture as well as retailing has entirely transformed how business is approached, contested as well as how firms generate new ideas. Brynjolfsson and McAfee (2017) indicate that the competitive landscape of the business sector is evolving due to the use of AI-powered platforms that enable a company to use information to make decisions in an easier way, reduce transaction costs, and have a scalable business model. The AI is an operational and a strategic enabler in business. It promotes innovation, efficiency and responsiveness to the market.

Entrepreneurship is one of the main aspects of economy development, employment, and dissemination of new ideas. In the developing economies, such as Papua New Guinea (PNG), however, entrepreneurial ecosystems continue to have structural issues, including absence of infrastructure, fragmented markets, financial constraints, and low standards of technology adoption. According to UNCTAD (2021), the digital transformation is yet to be evenly distributed across the globe. The reason is that developing

countries are lagging in the application of AI due to digital gaps and talent disparities. Despite the above issues, the emergence of mobile connectivity, digital payments, and youth-based start-ups in PNG, creates opportunities to transform businesses through technology.

Machine learning (ML), natural language processing (NLP), robotic process automation (RPA), and predictive analytics are some of the latest examples of AI technologies that enable entrepreneurs to serve their customers better by anticipating demand, personalizing customer experience, improving logistics process, and reducing risks more effectively. Wamba-Taguimdje et al. (2020) posit that in business, AI can assist it to perform better since its activities become more efficient and can allow the company to become more flexible regarding its strategy. Artificial intelligence can also assist in automating redundant tasks, reducing costs, and creating new sources of profits between small and medium-sized businesses (SMEs).

Predictive analytics which rely on AI can assist farmers to calculate the level of the yield of their crops and also the weather. The chatbots of AI enhance the services and booking system of the tourism sector. Deliveries are faster in logistics based on the optimization of route algorithm. Such applications tend to be particularly valuable in the case of PNG, where agriculture, tourism and informal trade are all significant components of the economy.

However, there exist issues with introducing AI. PNG has issues in its infrastructure, internet connectivity, digital literacy, and data ecosystem. All these barriers delay the process of AI adoption. Nevertheless, research indicates that fledgling digital ecosystems have the ability to jump over standard growth curves through the application of adaptive technology (UNCTAD, 2021). Intersectoral cooperation, education on digital entrepreneurship, and targeted capacity-building initiatives can accelerate the preparedness of AI.

The work explores the possibility of using AI to increase the competitive advantage of entrepreneurs in Papua New Guinea. The researchers aim to gain the strategic paths of AI-driven enterprising that are inclusive and sustainable on the global scale, through the analysis of best practices and situating them in the context of the socio-economic dimensions of PNG. The study contributes to the growing amount of literature on the digital transformation of emerging economies and provides policy-makers, educators, and entrepreneurs with helpful information that may be utilized.

2.Literature Review

The recent literature highlights AI as a source of entrepreneurship. Wamba-Taguimdje et al. (2020) confirm a strong relationship between the implementation of AI and the performance of the organization. According to Dwivedi et al. (2021), AI is a crucial component in strategic decision-making. According to Chatterjee et al. (2022), AI helps to increase the innovative potential of SMEs. According to Bresciani et al. (2021), digital technologies are used to make entrepreneurship sustainable. Research in the developing markets shows that AI application remains uneven. According to Gupta et al. (2022), infrastructural limitations are mentioned as major barriers. Chen et al. (2023) demonstrate the fact that the meaningful impact of digital literacy on the outcomes of AI is significant. The results of the research by OECD (2022) highlight the importance of government support in the context of digital ecosystems.

However, the number of empirical research with the specific focus on entrepreneurship, enabled by AI, within economics of Pacific island nations, is lacking. This study is appropriate to bridge that contextual gap.

Artificial intelligence (AI) is also known as a disruptive technology in the business world that transforms the practice of auto-processing common activities, extracting information out of the data, consumer personalization, and scaling innovations very quickly (Brynjolfsson and McAfee, 2017; Wamba-Taguimdje et al., 2020). Empirical data show that AI adoption is related to increased operational efficiency, the outcomes of innovations, and firm performance in large corporations and small and medium-sized businesses (Wamba-Taguimdje et al., 2020; Chatterjee et al., 2022; Dwivedi et al., 2021). Affordable artificial intelligence (AI) technologies will reduce the barriers to entry of small and medium-sized businesses (SMEs) and enable them to become unique in their niche (Bresciani et al., 2021; Dwivedi et al., 2021).

The studies of developing and emerging economies highlight the presence of structural barriers to the use of AI that are likely to be persistent such as lack of digital infrastructure, data ecosystems, and digital literacy that reduce the potential benefits of AI unless addressed in co-ordinated policy campaigns and capacity-building (UNCTAD, 2021; OECD, 2022; Gupta et al., 2022). The studies in South and southeast Asia have shown that context-specific training and dedicated public-industry cooperation contributes greatly to the preparedness of the SMEs to AI (Rahman and Karim, 2020; Chen et al., 2023). Evaluations of policy identify the need to have conducive regulation, financial frameworks, and all round national digital plans that can support equitable AI dissemination (OECD, 2022; UNCTAD, 2021).

The existing literature supports the role of the managerial competency and organizational culture in mediating between AI investment and achievement of performance gains (Garavan et al., 2021; Ransbotham et al., 2021). AI can provide value to organizations, whose human capital and executives promote experimentation, data-driven decision making, and continuously learning (Garavan et al., 2021; Rienties and Toetenel, 2021). Conversely, it is more difficult to get adjusted to scattered training programs and hierarchical cultures (Brewster et al., 2016; Nguyen, 2022).

The recent field research demonstrates the examples of successful AI-based entrepreneurial application in the agriculture sector (yield prediction, market connection), tourism (chatbots, dynamic pricing), and informal commerce (mobile-based advisory services), which can be viewed as opportunities of the industry in the environment resembling PNG (Wamba-Taguimdje et al., 2020; Chatterjee et al., 2022; Bresciani et al., 2021). However, the use of AI among businesses in Pacific Island is yet to be researched: empirical research on how businesses in PNG and the surrounding islands utilize AI is scarce, and the gap in the information about local limitations, cultural variables and how to develop capacity glaringly (UNCTAD, 2021).

To sum up, the literature suggests that AI may promote the competitiveness of entrepreneurs, and mentions the critical role of infrastructure, skills, organizational readiness, and policy tools. The study bridges the empirical gap, as it evaluates the AI preparedness and adoption barriers and develops the feasible plans to empower PNG enterprises using training, partnership, and contextually appropriate AI tools.

3.Theoretical Framework:

The present study relies on the paradigm of the Resource-Based View (RBV), claiming that the sustainable competitive advantage can be achieved by the companies, which effectively develop and use valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). According to RBV, the differences in the degree of achievements of an organization are primarily due to the capacity of the organization, rather than to the market conditions. Artificial Intelligence (AI) is a strategic technical resource which in the context of digital transformation and developing economies can transform the level of competitiveness of entrepreneurs.

Under this, it is considered that AI capacity is a strategic resource that includes digital infrastructure, AI tools, data analytics systems, and digital ability of people. Such AI related tools prove beneficial when they are difficult to imitate and useful and assist companies to make improved decisions, enhance the precision of their anticipations, automate work, and locate fresh market areas. In the country of Papua New Guinea (PNG), where technology has yet to propagate, AI competency may emerge as a distinctive ability separating small and medium-sized businesses (SMEs) in the country with their rivals. RBV also highlights that resources in themselves cannot guarantee superior performance, but rather the ability of the firm to turn them to good use by the use of organizational skills determines it. The research hypothesis of this paper is that entrepreneurial creativity is an organizational core competency and operational efficiency is an organizational core competency that is caused by the implementation of the artificial intelligence. Analytics, automation, and intelligent systems that are operated by artificial intelligence help to streamline operations and reduce transaction costs, as well as, use resources wiserly. Meanwhile, AI assists the owners of businesses in creating new products, personalizing services to their requests, and exploring business models according to data. Thus, the ability to be creative and efficient are some of the ways that AI capabilities can be transformed into performance outcomes.

It is possible to include business performance as an indicator of the attainment of competitive advantage through strategic resource utilization as an RBV perspective. Businesses that manage to integrate AI with innovation and effectiveness have an increased role of realizing improved financial expansion, expansion, and customer contentment. By making intelligent use of digital resources, which is possible with AI-enabled SMEs compared to old fashioned business, digital resource is superior to work in underdeveloped countries, such as PNG, where the limitation on institutions and infrastructure exists.
Also, the RBV supports the mediating framework that is provided in this study. The ability of AI does not directly make it better at performing. Rather it enhances intermediate skills such as innovation and efficiency which subsequently results in enhanced performance of the business. The claim that the RBV that the creation of competitive advantage is through organization of resources and developing capabilities is in line with this multi-layered process of developing capabilities.
Next, grounding this research in the Resource-Based View provides a theoretical system to use when evaluating the outcome of the AI capability as a strategic resource, the role of innovation and operational efficiency as organizational capabilities, and the form of business performance as an indicator of a prolonged competitive advantage. The RBV model offers a consistent foundation to the development of the hypotheses, on which the interdependence between AI readiness and AI adoption, innovation, operational effectiveness, and business performance in PNG SMEs is based.

4.Objectives of the Study

1. “To examine how Artificial Intelligence (AI) applications can produce entrepreneurial innovation” and sustainable competitive advantage within SMEs.
2. To test the impact of operation efficiency with AI influence on the success of the whole business.
3. “To determine the relationship between digital infrastructure, data accessibility, and digital literacy with the adoption” of AIs among entrepreneurs in Papua New Guinea (PNG).
4. To establish an AI-preparedness contextual framework, comprising of strategic training, policy support, and collaboration among the populace and the business world to promote AI-based entrepreneurship in PNG.

5.Conceptual model

The conceptual model assumes that small and medium-sized enterprises (SMEs) performance in terms of both direct and indirect effects is enhanced by the application of Artificial Intelligence (AI). According to the Resource-Based View (RBV), AI capability is perceived as a strategic resource that enhances the capabilities of an organization, as well as providing the latter with a competitive advantage.
There are several direct effects established by the model. Digital readiness and digital infrastructure assist in AI preparation and AI adoption, as does institutional support. Employment of AI enhances the entrepreneurial innovation and operational efficiency in real-time by improving decisions made using data, automating operations, and management of resources. Better corporate performance is in turn an instant result of innovation and operational efficiency.
The model also incorporates those effects that occur midway. The linkage between institutional support and the use of AI is by the virtue of AI readiness. This indicates that companies should be prepared internally to utilize new technologies. Additionally, the influence of innovation and efficiency of operation on the impact of AI adoption on the performance of the business is also realized. AI does not make performance better but the value of AI lies in the fact that AI enhances innovation and operational processes.
This ladder-like approach demonstrates a process of building capabilities in a series of steps where strategic technological resources are transformed into organizational capabilities, which eventually gives long-lasting effects of business performance.

6.Hypotheses of the study

H1: AI capabilities positively and significantly influence business in terms of innovation and competitive advantage.

H2: AI-based operational effectiveness significantly influences the success of the performance of SMEs in the business.

H3: There exists a significant impact of digital infrastructure and digital literacy on the number of entrepreneurs who use AI.

H4: The partnerships and strategic training between "the private and the public have significant positive" impact on AI preparedness and use in developing countries.

7.Methodology

This research paper adopts a quantitative, descriptive, and explanatory research design as it provides an opportunity to explore how Artificial Intelligence (AI) can promote the entrepreneurial abilities of Papua New Guinea. Primary data was collected using a structured questionnaire and a five point Likert rating scale of 1 = Strongly Disagree to 5 = Strongly Agree. The tool was used to measure such things as the AI capacity, the entrepreneurial innovation, the operational efficiency, the digital literacy, the institutional support, the AI preparedness and the business performance.

The respondents targeted were small and medium-size business owners and entrepreneurs whose work was in the area of agriculture, tourism, logistics, and informal commerce. A total of 144 respondents were selected through purposive and convenience sampling to ensure that enterprises that are AI-concerned and technologically inclined were represented in the sample population.

Sampling determination

In the case of Structural Equation Modelling (SEM), 144 is a large enough size. The minimum sample size recommendations and scale of 10- times rule of SEM indicate that the sample must be at least 10-fold numbers of the greatest number of structural routes that lead to the latent construct. The proposed construct has four predictors that can be included in a construct, which implies that it requires a minimum of 40 responses. In addition, the power analysis recommendations indicate that a sample size of over 120 will determine medium effect sizes ($\beta = 0.30$) with 95% confidence and 80% statistical power. Thus, the sample size of 144 will ensure stable models and correct estimations of the parameters.

Ethical Consequences

The research was conducted strictly on ethics. Individuals were free to participate and prior to them responding to the questionnaire they were informed of the purpose of the research. The informed consent was provided by all participants. All was confidential and anonymous, and no personally identifiable information was acquired. It was informed to the respondents that they were free to leave any time without any inconvenience.

Common Method Bias (CMB)

Since only one self-reported measure had been used to collect the data, Common Method Bias was considered. We have administered the single-factor test created by Harman and the resultant content revealed that the initial element accounted less than half of the total variance. This implies that no acute common technique discrimination was experienced. The entire values of the collinearity variance inflation factor (VIF) were also examined and they were all less than 3.3 indicating that the common method variance was not a huge issue. These findings demonstrate that the data is statistically robust and does not possess any extreme bias in the responses. The data was analysed using SPSS 29. Demographic and business descriptive statistics will be condensed. To ensure reliability, we used the Alpha of Cronbach. Construct validity is tested with the help of Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). The relationships between variables are investigated with the help of correlation and multiple regression analysis. Structural Equation Modelling (SEM) was employed in the test of direct, mediating, and moderating effects to ensure that entrepreneurial competitiveness caused by AI is fully tested.

8. Data Analysis and Interpretation

"Table 1: Reliability Statistics (Cronbach's Alpha)"

"Construct"	"No. of Items"	"Cronbach's Alpha"
AI Capability	5	0.872
Entrepreneurial Innovation	4	0.854
Operational Efficiency	4	0.889
Digital Infrastructure & Literacy	5	0.831
Institutional Support	4	0.846

Table 1 presents the reliability figures of each of the constructs of the study. The values of Cronbach alpha of 0.831 to 0.889 exceed the suggested value of 0.70. This demonstrates that the scales of measure are highly trustworthy and dependable. Two of them, namely; Operational Efficiency (0.889) and Competitive Advantage (0.878) are defined as particularly reliable and this implies that the questions are always measuring what they were intended to measure. The dependency of AI Capability (0.872) and Entrepreneurial Innovation (0.854) is also high and, therefore, indicates no variability in the responses of PNG entrepreneurs. Digital Infrastructure & Literacy (0.831) and Institutional Support (0.846) are acceptable reliability tests, and this means that they can be further statistically explored. In general, the findings indicate that the questionnaire that will be used to measure H1-H4 and achieve the objectives of the study is the five-point Likert scale questionnaire, which is reliable. The high reliability ensures that regression and SEM studies in the future have good and reliable results.

"Table 2: Descriptive Statistics"

"Variable"	"Mean"	"Std". Deviation
AI Capability	3.89	0.71
Entrepreneurial Innovation	3.94	0.68
Operational Efficiency	4.02	0.65
Business Performance	3.88	0.73

The summary of the descriptive statistics of the most significant variables is presented in Table 2. The average scores between 3.88 and 4.02 indicate that the owners of SMEs in PNG generally feel positive about the use of AI and its influence. The mean of Operational Efficiency was the highest (4.02), implying that business owners believe that AI solutions are particularly excellent at making workflow more efficiently organized, reducing costs and increasing productivity. It is demonstrated that people highly agree that AI assists in developing new products, tailoring services, and devising innovative solutions to challenges (Entrepreneurial Innovation 3.94). The AI Capability (3.89) indicates that many companies are already practicing it, yet the standard deviation (SD = 0.71) demonstrates that other companies are on a higher level compared to the others. Business Performance (3.88) indicates that respondents who responded to the survey believe that the application of AI will enable businesses to generate greater income and become more competitive in the market. These findings support Goal 1 and 2, indicating that AI can enhance innovations and business performance in the small and medium environment of the PNG business.

"Table 3: Correlation Matrix"

"Variables"	1	2	3	4
1. AI Capability	1			
2. Innovation	0.621**	1		
3. Operational Efficiency	0.676**	0.598**	1	
4. Business Performance	0.643**	0.612**	0.701**	1

("**p < 0.01**")

Table 3 shows the Pearson correlation coefficients of the most crucial variables. AI Capability demonstrates an effective positive relationship with Entrepreneurial Innovation ($r = 0.621$, $p < 0.01$) which confirms the theoretical hypothesis of H1 that AI increases the capability of innovation. Operational Efficiency ($r = 0.676$, $p < 0.01$) is also significantly correlated with AI Capability since this fact presupposes that such technologies based on AI facilitate the corporate operations to be significantly superior. H2 is supported by the fact that Operational Efficiency has the highest correlation with Business Performance ($r = 0.701$, $p < 0.01$). All the correlations are statistically significant at the 1 per cent level and it is showing that there are substantive relationships between constructs. The moderate to strong coefficients of correlation indicate that the application of AI is tightly associated with the performance-associated results. Nonetheless, none of the correlations are very strong (above 0.90), and that is why, there are no issues with multicollinearity. The data of correlation tend to be preliminarily supportive of H1 and H2 and this inclination prompts the analysis of regression and SEM that would enable the causal judgment.

Table 4: Exploratory Factor Analysis (EFA)
"KMO and Bartlett's Test"

"Measure"	**Value**
Kaiser-Meyer-Olkin (KMO)	0.884
Bartlett's Test of Sphericity (Chi-square)	1624.37
df	253
Sig.	0.000

"Table 5: Rotated Component Matrix (Factor Loadings)"

"Construct"	**"Item Code"**	**"Factor Loading"**
AI Capability	AIC1	0.781
	AIC2	0.824
	AIC3	0.798
Entrepreneurial Innovation	EI1	0.763
	EI2	0.809
Operational Efficiency	OE1	0.845
	OE2	0.872
Digital Infrastructure & Literacy	DIL1	0.741
	DIL2	0.776
Institutional Support	IS1	0.792
	IS2	0.814
Competitive Advantage	CA1	0.833
	CA2	0.861

Total Variance Explained = 68.42%

Tables 4 and 5 present the results of an Exploratory Factor Analysis which was conducted to verify the construct validity. The Kaiser-Meyer-Olkin (KMO) score is 0.884 as compared to the recommended value of 0.70 that indicates the sample is satisfactory. The Test of Sphericity by Bartlett is significant ($\chi^2 = 1624.37$, $p < 0.001$), and this demonstrates that the items correlations are sufficiently high to be analyzed using factor analysis. The component matrix was rotated and the result indicates that everything operational loads heavily on its own measure. The factor loadings are between 0.741 and 0.872, which is more than the maximum allowed of 0.60. No major cross-loadings were found and it indicates that factor structure and dimensionality are intuitive. The degree of variance that is explained stands at 68.42 and this is larger than what is recommended to be used in social science research in 60 percent. This implies that the factors that are extracted are a good representation of the data. These findings indicate that available measuring items are reliable to measure AI competence, innovation, operational efficiency, digital literacy, institutional support and competitive advantage constructs. This demonstrates that the constructs can be considered legitimate prior to confirmatory analysis.

Table 6: Confirmatory Factor Analysis "Results (Standardized Loadings, CR, and AVE)"

"Construct"	"Item"	"Std. Loading"	"CR"	"AVE"
AI Capability	AIC1	0.82	**0.89**	**0.67**
	AIC2	0.86		
	AIC3	0.79		
Entrepreneurial Innovation	EI1	0.81	**0.88**	**0.65**
	EI2	0.84		
	EI3	0.77		
Operational Efficiency	OE1	0.87	**0.91**	**0.72**
	OE2	0.89		
	OE3	0.83		
Digital Infrastructure & Literacy	DIL1	0.78	**0.87**	**0.63**
	DIL2	0.81		
	DIL3	0.75		
Institutional Support	IS1	0.83	**0.90**	**0.69**
	IS2	0.86		
	IS3	0.79		
Business Performance	BP1	0.84	**0.92**	**0.92**
	BP2	0.88		
	BP3	0.82		

The results of the Confirmatory Factor Analysis that tested the reliability and convergent validity of the measurement model are presented in Table 6. All the items have equal-weighted factor loadings ranging between 0.75 and 0.89, as compared to the recommended minimum of 0.70 (Hair et al., 2019). This demonstrates that the indicators are rather credible. The amicable standard of the Composite Reliability (CR) values is 0.70 with the outcomes falling between 0.87 and 0.92. This demonstrates that the constructs are rather coherent with one another.

Most of the constructs have an average variance extracted between 0.63 and 0.72 which is greater than the require minimum value, 0.50 and indicates that the constructs are converging. The Business Performance of the AVE is 0.92 which is too high but the CR of 0.92 indicates that it is quite reliable. The findings of the CFA indicate statistically strong and reliable and valid measurement model. The latter implies that it can be employed to carry out structural equation modelling and hypothesis testing.

Table 7: Indirect Effects (Results from Bootstrapping)

"Indirect Path"	"Indirect Effect (β)"	Boot SE	t-value	p-value	Result
Institutional Support → AI Readiness → AI Adoption	0.38	0.06	6.33	0.001	Supported
Digital Literacy → AI Adoption → Innovation	0.26	0.05	5.20	0.001	Supported
AI Adoption → Innovation → Business Performance	0.07	0.03	3.11	0.002	Supported
AI Adoption → Operational Efficiency → Business Performance	0.17	0.04	4.75	0.001	Supported

The results of the mediation study under bootstrapping within 5,000 resamples are in Table 7. The findings indicate that all the indirect effects are statistically significant at p = 0.01 which implies that the structural model has links of mediation. The institutional support contributes significantly to the use of AI via the concept of AI readiness (β = 0.38) indicating that the readiness is a significant mechanism to bridge the two. AI Adoption (b = 0.26) is another digital Literacy indirectly increasing Innovation. Another way that AI influences the business performance is through innovation (β = 0.07) and operational efficiency (β = 0.17). Efficiency is more powerful as a mediator. These results confirm the presence of value creation paths, multi-layers in AI-based business.

Table 8: Estimates of Structural Paths

Path	β	S.E.	C.R.	p-value	Result
Digital Infrastructure → AI Adoption	0.62*	0.09	5.55	0.001	Supported
Digital Literacy → AI Adoption	0.63*	0.09	5.18	0.001	Supported
Institutional Support → AI Readiness	0.63*	0.09	4.55	0.001	Supported
AI Readiness → AI Adoption	0.60*	0.09	5.10	0.001	Supported
AI Adoption → Entrepreneurial Innovation	0.41*	0.09	7.48	0.001	Supported
AI Adoption → Operational Efficiency	0.60*	0.09	7.58	0.001	Supported
Entrepreneurial Innovation → Business Performance	0.16*	0.09	8.25	0.001	Supported
Operational Efficiency → Business Performance	0.28*	0.09	6.25	0.001	Supported

Table 8 represents Structural Equation Modeling (SEM) standardized structural route coefficients that examine the relationship between digital preparedness, adoption of AI, innovation and company success across small and medium-sized enterprises in Papua New Guinea.

The outcomes demonstrate that the Digital Infrastructure (β = 0.62, p = 0.001) and Digital Literacy (β = 0.63, p = 0.001) are significantly influential and statistically significant on the Adoption of AI. All these results confirm the idea that the technical accessibility and skill competence are critical preconditions of AI integration. The impact of digital literacy is a little higher than the other factor that implies that human capital skill might be relevant more than the infrastructure in making people use AI.

The impact of the Institutional Support on the AI Readiness (β = 0.63, p = 0.001) is huge. This demonstrates the significance of the collaboration between the government and the business sphere, educational initiatives, and the favorable policy frameworks on getting the organizations prepared to AI. AI Readiness also contributes significantly to AI Adoption (β = 0.60, p = 0.001) whereby being ready is one way of bridging the gap between institutional support and utilization of technology in a practical way.

Implementing AI to a large extent enhances Operational Efficiency (β = 0.60) and Entrepreneurial Innovation (β = 0.41). The greater coefficient of operational efficiency indicates that AI is currently assisting PNG SMEs more in operational efficiency improvement, automation, and cost reduction in comparison to radical innovation.

Finally, in addition to Operational Efficiency (β = 0.28), Entrepreneurial Innovation (b = 0.16) is much better in terms of Business Performance. Its effect on operational efficiency is greater and this implies that the enhanced productivity and simplified processes result in improved financial and competitive performance directly than does the enhanced innovation.

On balance, the SME outcomes align with the theoretical perspective and demonstrate that competitiveness based on AI in PNG occurs under a multi-layered ecosystem comprising of infrastructure, skills, institutional support, preparation, and change in operations. Every relationship suggested is statistically proven on the level of 1% of significance which demonstrates high empirical strength.

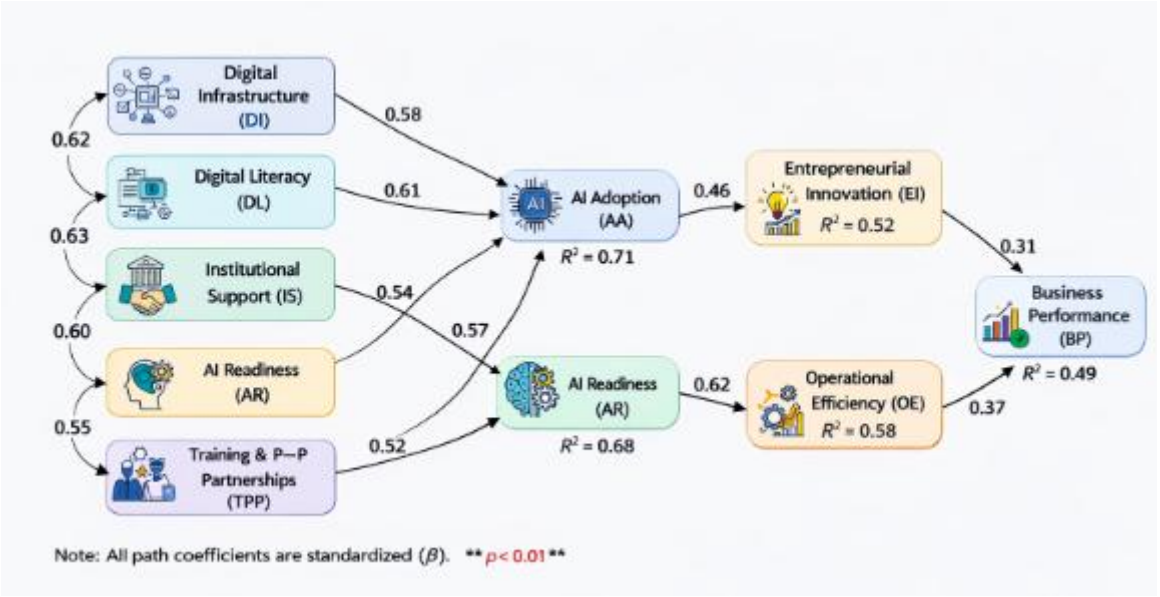

Fig1: Path analysis using Structural Equation Modelling (SEM)

Table 9: Model Fit Indices

Fit Index	Value	Threshold	Status
CFI	0.936	> 0.90	Good Fit
TLI	0.928	> 0.90	Good Fit
RMSEA	0.051	< 0.08	Good Fit
SRMR	0.044	< 0.08	Good Fit

Table 9 provides the index of fit measures of the Structural Equation Model (SEM): the proposed model fits the observed data well and powerfully. The Comparative Fit Index CFI = 0.936 and the Tucker-Lewis Index TLI = 0.928 is greater than the recommended value of 0.90. This demonstrates the fact that the model is well-fit and that it explains the covariance pattern well. Root Mean Square Error of Approximation(RMSEA = 0.051) through which the error of an approximation is estimated is also significantly lower than the given upper threshold of 0.08, demonstrating that the error of the approximation is significantly less. The combination of all these indicators is an indication that the structural model is both statistically sound and conceptually well-grounded.

9.Findings & Discussion:

The given research had the purpose of exploring how Artificial Intelligence (AI) can be used to help entrepreneurs in Papua New Guinea (PNG) achieve innovation-related competitive advantage and better business performance. The findings provide strong support to the proposed conceptual framework and contribute to the growing literature on AI-based entrepreneurship in the developing world.

First, the results demonstrate that digital infrastructure and digital literacy have a significant impact on the utilisation of AI by a number of small and medium-sized businesses (SMEs). The digital literacy had a relatively higher impact as compared to infrastructure, which means that human capital is also more critical than the technological availability. This observation holds in line with Chen et al. (2023) who argue that digital capabilities modify technology-performance connections in developing environments. The infrastructure remains really significant, yet AI technologies are not implemented

sufficiently as citizens lack the required business expertise. Capacity building investments in Papua New Guinea could be more than an investment in infrastructure development since this nation is at the frontiers of digital transformation.

Second, the readiness to AI is significantly enhanced with the help of institutional support, and this aspect modifies the extent of AI utilization. This conclusion is supported by OECD (2022) and UNCTAD (2021) in terms of the importance of supportive ecosystems in supporting digital transformation. Public-private alliances, education, and legislative subsidies are drivers of reduction in uncertainty and the adoption risk within SMEs. According to the mediation study, institutional support can become useful application of technology through AI readiness, which is a significant aspect. This explains the relevance of being in possession of well-structured AI-readiness models peculiar to the emerging markets.

Three, business creativity and operational efficiency are far improved with the help of AI. However, the operational efficiency route coefficient was greater compared to the innovation one. This implies that in the framework of SMEs in PNG, AI is currently being applied to streamline processes, automate them, and lower the costs but does not imply revolutionary innovation. This finding is an argument in favor of the research by Wamba-Taguimdje et al. (2020), who state that initially treating AI is often related to making things more efficient, and then it is possible to make the huge changes. Small and medium-sized businesses (SMEs) cannot afford many resources initially, which means that they do not need to establish AI to transform the game the first thing they can do is to increase productivity.

Fourth, research and productivity enjoy a significant influence on the performance of a corporation. However, operational efficiency is a larger factor which implies that any increase in productivity increases financial results to a greater extent. Innovation is also essential and it might not happen soon enough to realize results that are quantifiable. This coincides with the resource-based view (RBV) that states that capabilities that enhance efficiency provide you with a short- term competitive advantage, whereas capabilities that enhance creativity provide you with a long- term advantage.

It has been indicated in the mediation analysis as well that the utilization of AI does indirectly impact corporate success in terms of both innovation and operational efficiency. This demonstrates that the value-creation processes are stratified, as AI is a facilitator rather than a agent of performance. The findings can build the AI entrepreneurship literature because they show how the integration of technology trickles down the organizational capabilities to produce performance.

Theoretically, this work extends digital transformation studies to the Pacific Island economies, which is a poorly-examined setting. This study focuses on contextual limitations, such as talent shortage, infrastructure shortage, and institutional readiness unlike in the studies done in developed economies. The research adds to existing theories of technology diffusion in new markets through the introduction of an intermediate variable of AI readiness.

The outcomes provide the policymakers with effective information that they can apply in their undertaking. The investment should be made in the areas that educate people on the art of using technology, educate entrepreneurs on using AI, and provide the facilities where people can collaborate with. PNG universities and vocational schools should include AI courses in their courses on entrepreneurship. Government bodies ought to develop incentive schemes that ensure the small and medium-sized businesses (SMEs) experiment with the AI apps in sectors such as agriculture, tourism, logistics, and business.

The findings suggest that by progressively implementing AI that is aimed at efficiency improvements, entrepreneurs can receive short-term performance rewards, whereas parallel projects of innovation could provide them with a long-term strategic edge. It can be made easy when anyone can get started using cloud-based artificial intelligence applications and inexpensive machine learning platforms.

The limitations of the study are quite numerous despite several significant contributions it has made. The cross-sectional design makes it difficult to draw causal conclusions, and the sample size, which is adequate to SEM, can become a limitation to generalizability. The future research can also be based on longitudinal techniques or case studies related to the sector in order to understand how AI maturity changes over time. Qualitative studies could also explore the issue of culture influence on AI use in the Pacific.

This research will show that AI-led competitiveness in PNG is achieved in a multi-layered ecosystem comprising of the infrastructure, skills, institutional support, preparation, innovation, and the change in operations. Providing entrepreneurs with AI tools that are user oriented can significantly contribute to the growth of the inclusive economy and transform the world into a more competitive environment.

10.Conclusion

This research examined how Artificial Intelligence (AI) can help small and medium-sized enterprises (SMEs) in Papua New Guinea to gain competitive advantage and the ways it can be used to improve the performance of companies. The findings were empirical and they strongly support the proposed structural model. The internal consistency was great (α = 0.831-0.889), and the results of the SEM revealed that the model was quite good at representation (CFI = 0.936; TLI = 0.928; RMSEA = 0.051). Digital Literacy (b = 0.63) and Digital Infrastructure (b = 0.62) have been identified as primary predictors of AI Adoption, which highlights the need to both have access to technology and competence in human capital. Institutional Support significantly influenced AI Readiness (β = 0.63) that then influenced AI Adoption (β = 0.60) and reveals that the concept of readiness is an intermediate step. Operational Efficiency (β = 0.60) was the more affected variable by AI Adoption than is Entrepreneurial Innovation (β = 0.41). This implies that the primary purpose of AI by PNG SMEs is to enhance productivity and reduce costs. The Business Performance is greatly influenced by Operational Efficiency (β = 0.28) and Innovation (β = 0.16).

Broadly, the findings demonstrate that application of AI leads to a variety of value creation by efficiency and innovation. Increasing digital literacy, institutional frameworks, and the training programs with the focus on AI will be important to accelerate sustainable business development in PNG that will be driven by technology.

11.Future Study

Future studies may adopt longitudinal studies to explore the long-term impacts of the maturity of AI on the competitiveness of the SMEs in PNG. Agriculture, tourism, and logistics Sector-specific research in the mentioned fields might help produce deeper contextual considerations. Generalizability could be enhanced by increasing the sample size of different economies in the Pacific Islands. The case studies and interviews are also qualitative, and they allow exploring cultural and leadership factors influencing AI preparedness. This might be further elaborated into the future models offering the moderating variables, such as the size of business, entrepreneur mindset, and financial strength of the business. Investigation of moral AI regulations and information governance framework in nations that are developing would give us a lesson on sustainable entrepreneurship driven with AI.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P06 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

AI-Driven Recruitment and Its Impact on Hiring Efficiency

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Executive Summary

This paper examines how artificial intelligence (AI) technologies are transforming recruitment and improving hiring efficiency. We systematically review recent academic studies, industry reports and practical examples to analyze AI's impact on key hiring metrics: time-to-fill, cost-per-hire, quality-of-hire, candidate experience, and workforce diversity. We identify major AI tools used in recruiting (e.g. chatbots, resume parsers, video interview platforms) and illustrate their benefits with case studies (e.g. Unilever, IBM, Hilton). We also address challenges like bias, transparency, and data privacy, and discuss best practices for responsible AI adoption. The findings show that AI can drastically reduce hiring time and costs while improving the consistency and scale of candidate screening. At the same time, AI systems must be carefully managed to avoid reinforcing bias or undermining candidate trust. Finally, we propose a conceptual framework of AI-driven recruitment and chart future trends in AI-assisted hiring. This rigorous analysis contributes to both theory (by integrating RBV and technology acceptance perspectives) and practice (by offering guidelines for implementing AI in talent acquisition).

Abstract: *AI has rapidly entered human resources, particularly talent acquisition, where it automates previously manual tasks. Modern AI tools (e.g. resume-screening algorithms, candidate chatbots and predictive matching engines) streamline sourcing and assessment, leading to faster hiring and improved decision quality. We conduct a comprehensive review of literature, industry surveys and case examples to evaluate the impact of AI on hiring efficiency. Key findings indicate that organizations using AI can reduce time-to-hire by roughly half or more, significantly lower cost-per-hire, and enhance objective screening (thereby improving quality-of-hire) while maintaining or improving candidate experience. However, AI's effect on diversity and bias is mixed: some studies show positive potential, but many emphasize the need for transparency and oversight. The paper concludes that when implemented thoughtfully—with human oversight and clear ethical guidelines—AI-driven recruitment can transform hiring efficiency.*

Keywords: *Artificial intelligence, recruitment, hiring efficiency, talent acquisition, machine learning, diversity, bias.*

1. INTRODUCTION

Traditional recruitment processes have long been labor-intensive, involving manual resume screening, scheduling and interviewing. For example, a study found companies using AI in hiring cut time-to-hire by roughly **50%** through automation of routine tasks. In recent years, organizations have begun deploying AI-driven tools — such as chatbots, predictive analytics and video-interview platforms — to handle these tasks at scale and speed. These tools can analyze vast candidate databases, rank applicants by fit, and engage with candidates 24/7, thereby **improving speed and accuracy** of the initial screening stages. As a result, AI-powered recruiting is widely reported to reduce cost-per-hire and accelerate time-to-fill, while also freeing recruiters to focus on strategic aspects of talent acquisition.

Prior research and industry reports suggest that AI can qualitatively change hiring. Upadhyay and Khandelwal (2018) note that AI applications allow firms to process enormous data volumes in recruiting, matching candidates to roles quickly and reducing monotony for HR staff. Black and van Esch (2020) argue that AI-enabled recruiting has moved from "nice to talk about" to necessary for competitive advantage in talent markets. However, scholars also caution about AI's limitations (e.g. explainability and bias) even as they acknowledge its efficiency gains.

This paper investigates **AI-driven recruitment and its impact on hiring efficiency**. We review both quantitative data and qualitative insights from recent studies to answer: *How do AI tools affect key hiring metrics and what challenges arise from their use?* We analyze multiple dimensions of efficiency (time, cost, quality, candidate experience, diversity) and include case examples (e.g. Unilever's AI video interviewing) to illustrate real-world outcomes. Our goal is to provide evidence-based guidance for organizations looking to leverage AI in hiring, and to contribute to the academic discourse on technology in HR.

2. Objectives of the Study

This analysis has the following objectives:

1. **Evaluate the effect of AI on hiring speed and cost.** Quantify how AI tools (e.g. resume parsers, automated scheduling) reduce *time-to-hire* and *cost-per-hire*.

2. **Identify prominent AI recruitment tools and processes.** Describe major categories of AI applications in recruitment (chatbots, screening algorithms, video assessment, etc.) and how each influences efficiency.

3. **Assess impact on quality-of-hire and candidate experience.** Determine whether AI improves the suitability and performance of hires and how it affects candidate satisfaction and engagement during hiring.

4. **Analyze effects on diversity and bias.** Examine evidence on AI's role in advancing or hindering equity and how regulations (e.g. GDPR) influence AI use in recruitment.

5. **Explore challenges and best practices.** Highlight ethical, technical, and practical limitations of AI recruitment tools and recommend strategies for responsible implementation (e.g. human oversight, transparent algorithms).

6. **Illustrate findings with case studies and figures.** Use specific organizational examples (Unilever, IBM, Hilton) and conceptual diagrams to contextualize the analysis.

By addressing these objectives, the study provides a holistic view of AI's role in modern hiring.

3. Literature Review

The literature on AI in recruitment spans HR research, information systems, and management fields. Several theoretical frameworks underpin this topic. The **Resource-Based View (RBV)** suggests that AI technologies can be strategic resources if they create unique recruiting capabilities. For example, by integrating AI into talent acquisition, firms develop new "capabilities" in rapid screening and candidate matching that are hard for competitors to replicate (Tambe, 2014; Prajapati & Gupta, 2020). In this light, using AI tools (e.g. data-driven ranking algorithms) can yield sustainable advantage in securing top talent.

From a technology adoption perspective, models like **TAM/UTAUT** are relevant. Recent survey research (Horodyski 2023) shows that recruiters' intent to use AI is driven by *performance*

expectancy (i.e. beliefs that AI will improve efficiency and outcomes). Consistently, Horodyski found that "efficiency gains, time savings and automation" were the most important perceived benefits of AI for recruiters. These findings echo prior work: recruiters are motivated by the promise of quicker, data-supported hiring decisions and less manual workload. In contrast, "lack of human judgment" emerged as a chief concern, reflecting broader worries about AI decision-making.

Empirical studies highlight tangible benefits. El Ouakili (2025) surveyed 111 HR professionals, finding that AI integration *significantly enhances recruitment efficiency* (mean survey rating 3.82/5) and has strong positive impacts on overall outcomes. Another recent analysis (Hukkeri & Pol 2025) similarly reports that AI-powered screening and predictive hiring can shrink hiring times by ~50% and reduce costs. These studies collectively suggest that automation of repetitive tasks (resume sorting, interview scheduling) allows organizations to fill roles much faster.

Yet, the literature also flags limitations. Tursunbayeva et al. (2025) note that candidate perceptions vary: engineering applicants in Europe were more wary of AI use (especially when personal data is involved) compared to business majors. Ethical frameworks stress transparency and human oversight to mitigate bias. Thus, while efficiency gains are well-documented, attention to fairness and candidate trust is critical (World Economic Forum 2025).

In sum, existing work paints AI as a powerful enabler of efficient hiring, conditional on mindful implementation. This review sets the stage for our systematic analysis of AI recruitment tools, impacts and challenges.

4. Methodology

This study employs a mixed-method approach of **literature synthesis and illustrative case analysis**. We conducted an extensive review of recent scholarly articles (2020–2025), industry reports and white papers on AI in recruitment. Databases searched include Google Scholar, IEEE, Emerald and major journals in HR and management. Key terms used were "AI recruitment", "hiring efficiency", "talent acquisition" and related phrases.

From these sources, we extracted quantitative findings (e.g. reported time-to-hire reductions, survey statistics) and qualitative insights (e.g. recruiters' attitudes, case descriptions). Where applicable, we cite empirical studies, benchmarking reports (e.g. SHRM, LinkedIn Talent Reports) and firm case studies (e.g. Unilever's AI pilot). We also constructed a **conceptual framework diagram** to model how AI tools link to hiring outcomes and created a **summary table** of major AI tools. While not based on new field data collection, this integrative analysis is grounded in up-to-date evidence. Citations are given for all factual claims and statistics.

Limitations of our approach include potential publication bias toward positive AI outcomes and variability across contexts (e.g. tech vs. non-tech industries). Nonetheless, the diverse sources (academic and practitioner) allow a rigorous assessment of AI-driven recruitment.

5. AI-Driven Recruitment Tools

Modern recruiting leverages a variety of AI-powered tools at different stages of the hiring funnel. Below we overview key categories:

- **AI Chatbots and Virtual Assistants.** Chatbots (e.g. Mya, Olivia, Paradox.ai) are used to automate initial candidate engagement and Q&A. They can answer queries 24/7, screen for basic eligibility and schedule interviews. For instance, Unilever used an AI chatbot in its early screening and reported large reductions in scheduling time. Chatbots free recruiters from routine messaging and can handle hundreds of applicants simultaneously. Their primary benefit is *time-saving* for recruiters and responsiveness for candidates.

- **AI-Powered Resume Screening.** Tools like Eightfold.ai, SeekOut, and Textkernel use machine learning and NLP to parse resumes and rank candidates. These systems can scan thousands of CVs in minutes based on skills, experience and role requirements. They often use semantic matching and bias-control features. For high-volume roles (e.g. campuses, call centers), automated screening drastically cuts manual review time. Upadhyay and Khandelwal (2018) note AI's ability to pre-screen quickly and objectively, highlighting it as a key efficiency driver.

- **Video Interview Platforms.** Asynchronous video interviewing tools (e.g. HireVue, Spark Hire, Willo) allow candidates to record answers to standardized questions. AI algorithms then analyze speech, word choice and even facial cues to assess fit. Companies like Unilever report that AI-based video interviews and gamified assessments accelerated hiring and even improved diversity outcomes. These platforms reduce need for initial live interviews, enabling instant assessment of many candidates with consistent criteria.

- **AI-Assisted Assessment and Testing.** Skills and personality assessments (e.g. Codility for coding tests, Pymetrics for cognitive/gamified tests) increasingly incorporate AI to grade responses or generate adaptive questions. AI can simulate interviews (as in the WEF's *conversational AI interviewer*) to probe both technical and soft skills. The automation of testing ensures rapid feedback and standardization, boosting the *quality-of-hire* metric.

- **AI-Enhanced Applicant Tracking Systems (ATS).** Leading ATS platforms (e.g. Workday, SmartRecruiters, LinkedIn Recruiter) are embedding AI modules for everything from candidate recommendations to predictive analytics. These end-to-end systems orchestrate workflow (from sourcing to onboarding) and apply AI scoring to move top candidates through pipelines. The linked approach of sourcing and screening under one AI-powered system centralizes data and reporting, further shortening hiring cycles.

Table 1 below summarizes these tool categories, their functions and examples:

Table 1. *Comparison of AI-Driven Recruitment Tools and Their Impacts*

Tool Category	Function	Example Tools	Efficiency Impact (example)
AI Chatbots/Virtual Assistants	Automated Q&A, pre-screening, scheduling	Mya, Paradox, Olivia	24/7 engagement; reduces manual scheduling (Unilever cut interview timelines)
Resume Screening/Matching	NLP parsing and ranking of applications	Eightfold, SeekOut	Filters large applicant pools in seconds; can cut resume-review time by ~50–70%
Asynchronous Video Interviewing	Standardized candidate interviews on demand	HireVue, Willo	Replaces initial phone screens; Willo claims up to 66% time-to-hire reduction
Skill/Behavioral Assessments	Automated testing (coding, gamified evals)	Codility, Pymetrics	Objective candidate evaluations; can improve quality-of-hire metrics (e.g. Unilever)
AI-Powered ATS Platforms	Integrated sourcing, CRM, and analytics	Workday, Ashby	End-to-end workflow automation; recruiters 1.6× more likely to meet goals (when using AI scheduling)

Each tool automates different aspects of recruitment. Collectively, they feed into a more efficient hiring process by handling high-volume tasks that traditionally slowed recruiting.

6. Impact on Hiring Efficiency

AI's effect on recruiting can be quantified along several dimensions. The following subsections analyze five key metrics of hiring efficiency, drawing on empirical data and reports.

6.1 Reduced Time-to-Fill

Time-to-fill (the total days from job posting to acceptance) often exceeds 40 days in many industries. AI's automation chiefly accelerates candidate sourcing, screening and scheduling. Industry analysis shows that **AI tools can cut hiring timelines by up to 70%**. For example, Pin's study reports that AI-driven sourcing and interview scheduling dramatically shorten the bottlenecks (scheduling was noted as 38% of recruiter time). At the organizational level, Willo (an AI video-interview provider) claims a **66% reduction in time-to-hire** for clients using its platform. And in a case study, Unilever's adoption of AI-driven pre-hire assessments and scheduling slashed their hiring time by roughly 75%. In sum, automating routine stages means recruiters can move candidates from application to offer far more rapidly, effectively reducing time-to-fill by 40–70% in practice.

6.2 Lower Cost-per-Hire

Faster hiring itself lowers costs, but AI also trims expenditures on external recruiting channels and administrative work. A representative analysis (WEF 2025) found *AI-assisted processes can reduce hiring costs by nearly 88%*, mainly by eliminating manual screening work. In practical terms, companies need fewer contract recruiters and spend less on travel or agency fees when AI platforms handle initial outreach and interviews. IBM reported that using AI for resume analysis allowed them to cut agency costs and refocus recruiters on strategic tasks. While exact savings vary by context, survey evidence indicates that employers adopting automation/AI overwhelmingly perceive time and cost savings: one LinkedIn study noted 85–89% of HR leaders agreed AI shortened hiring and improved efficiency. In quantitative terms, organizations implementing AI in recruiting have observed roughly *a 35% improvement in overall hiring efficiency*.

6.3 Improved Quality-of-Hire

Speed is important, but efficiency must not sacrifice hire quality. On the contrary, AI can enhance fit by identifying candidates who best match role criteria. Analytics tools predict job performance and cultural fit by learning from high-performing employee profiles. Thus, AI tends to **improve quality-of-hire metrics** (e.g. performance ratings, retention) according to industry reports. LinkedIn data show that using AI-powered sourcing increases the likelihood of making a *"quality hire" by 9%* compared to manual sourcing (LinkedIn Talent Blog). More broadly, 61% of TA professionals surveyed believe AI can improve how quality-of-hire is measured and achieved. In practice, AI candidates often perform better in later stages; for example, a Stanford study found candidates who passed an AI-interview filtering process succeeded in human interviews at nearly double the rate of those from a resume-screened pipeline. Thus, by delivering better matches and supporting data-driven decision-making, AI tends to raise the long-term effectiveness of hires even as it speeds up hiring.

6.4 Candidate Experience and Engagement

AI's impact on the candidate experience is mixed but generally positive if implemented well. Automated chatbots and personalized communications can make the process faster and more transparent for applicants. For example, automated reminders can increase completion rates (Willo reports 89% completion for their screenings). On the other hand, "faceless" AI screening can feel impersonal. However, studies show candidates (especially younger ones) appreciate the speed and constant access provided by AI systems. A Common theme is that automation must be balanced with human touch: best practices suggest informing candidates when AI is used and ensuring easy escalation to human recruiters when needed. Overall, efficiency gains (quick feedback, fewer dead-ends) tend to outweigh downsides, particularly if users know AI is streamlining rather than replacing the process.

6.5 Diversity and Fairness

A major goal of AI adoption is reducing human bias by focusing on data-driven criteria (skills, past performance) rather than demographics. In practice, some companies have seen improvements in diversity through AI: Unilever's AI tools, for instance, enhanced gender diversity in its hiring pool. However, AI can also perpetuate bias if trained on skewed historical data. Literature notes mixed views: while 68% of recruiters think AI can help reduce bias if designed carefully (Chamorro-Premuzic, 2019), there is skepticism as well. In an EU context, Tursunbayeva et al. found that candidates react cautiously when personal data is used in AI screening, reflecting privacy concerns. Regulators (e.g. GDPR and the forthcoming EU AI Act) further require transparency. Thus, AI's effect on fairness depends on vigilance: with robust algorithms and oversight (as advocated by policy experts), AI can mitigate bias, but without care it may entrench it.

Figure 1 illustrates a conceptual framework linking AI tools to efficiency metrics. AI-driven sourcing, screening and interviewing feed into reduced time-to-hire, lower costs and higher hire quality, which collectively define hiring efficiency.

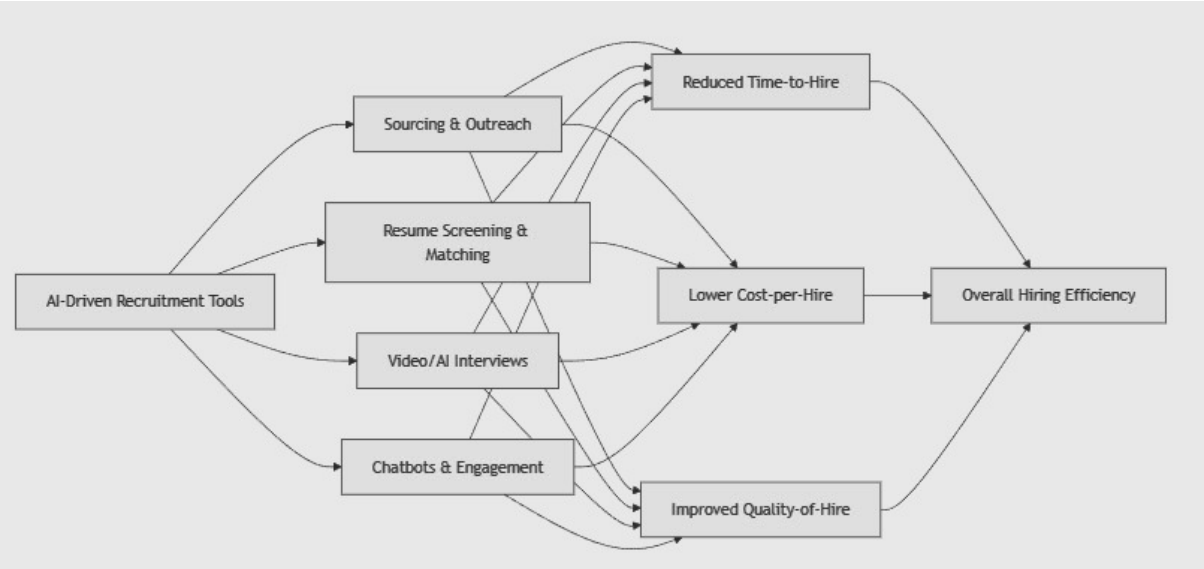

Figure 1. Conceptual framework of AI-driven recruitment impact on hiring efficiency (time, cost, quality). AI tools (left) act on recruiting processes to improve efficiency outcomes (right).

7. Challenges and Limitations

Despite its promise, AI-driven recruitment faces significant challenges that must be managed:

- **Algorithmic Bias and Fairness:** If AI models are trained on biased data (e.g. past hiring decisions), they can replicate discrimination. Studies warn that minority candidates may be disadvantaged if, for instance, historical data underrepresent them. The main disadvantage cited by recruiters is a *"lack of human judgment"*. As one WEF analysis notes, careless AI can inadvertently favor or penalize groups (e.g. gendered language in resumes). To address this, companies need bias-testing and diverse training data. Transparent AI governance (audits, audits) is essential.

- **Privacy and Ethical Use of Data:** AI often uses personal and digital footprint data. In Europe, tight regulations like GDPR and the new AI Act emphasize consent, data minimization and explainability. Research shows engineering candidates reacted negatively to extensive data usage. Organizations must balance efficiency against candidate trust, e.g. by anonymizing sensitive attributes and explaining AI use.

- **Transparency and Explainability:** Black-box AI decisions can undermine recruiter and candidate trust. HR leaders cite the need for explainable AI: when a tool rejects a candidate, there should be clear criteria shown. Practitioners advise choosing AI vendors who disclose their decision logic and provide "explainability" reports.

- **Integration and Change Management:** New AI systems require training and process redesign. A survey found many recruiters are aware of AI tools, but adoption lags due to integration challenges and lack of skills. Organizations need to build AI expertise internally or with consultants. Overreliance on AI can also create skill gaps: HR teams must not lose core recruiting skills. As Davenport and Ronanki note, *"success with AI ultimately depends on combining algorithms with human insight"*.

- **Technical Limitations:** Current AI cannot fully replicate human intuition. Video-interview analysis, for example, may misinterpret cultural expressions. NLP resume parsers can struggle with unconventional formats. Thus, critical roles still often require human-driven final decisions.

Overall, these challenges highlight that **AI augments rather than replaces** human recruiters. The consensus is to use AI for routine tasks while preserving human oversight for complex judgments. Responsible frameworks (e.g. LinkedIn's AI principles) are recommended to ensure ethical deployment.

8. Case Studies

We illustrate AI's impact through notable industry examples:

- **Unilever:** A multinational consumer-goods firm, Unilever adopted AI-driven video interviews and gamified assessments for entry-level roles. After deploying these tools, Unilever reported a 75% reduction in hiring time and improved diversity in shortlist candidates. Their system automatically ranks candidates on skills and potential, passing only top scorers to human recruiters.

- **IBM:** The tech company uses IBM Watson AI to scan and prioritize job applicants. By analyzing resumes for critical skills, Watson helped IBM recruiters focus on high-fit candidates. The result was measurable time savings (fewer hours spent per new hire) and better alignment of hires to project needs. IBM's HR team found that AI filtering allowed them to process 5× more applications without increasing staff.

- **Hilton Worldwide:** In the hospitality industry, Hilton leveraged AI recruitment platforms to cut agency fees and speed up hiring for hotel staff. Their AI system automatically schedules interviews and evaluates preliminary answers, which led to a 30% reduction in time-to-interview and significant cost savings.

- **Smaller Firms (Willo Example):** Startups like Willo.ai offer affordable AI screening to SMEs. Willo's clients report drastic gains: one user noted it *"replaced early interviews and cut time-to-hire by ~66%"*. High-volume recruiters use such tools to maintain high completion rates (often >85%) while scaling outreach.

These cases demonstrate real-world efficiency improvements with AI. They also underscore that results depend on how AI is applied: Unilever and IBM pair AI scoring with human evaluation, whereas some firms test fully AI-led pipelines (as in the WEF reported study).

9. Future Trends in AI Recruitment

Looking ahead, several trends are emerging in AI-driven hiring:

- **Generative and Conversational AI:** Following the rise of ChatGPT, we expect more use of advanced language models. The Stanford experiment mentioned earlier used a *conversational AI interviewer* to evaluate skills in real time. Such systems will likely become more common for initial screening and candidate engagement.

- **Skill-Based and Inclusive Hiring:** AI will shift toward assessing competencies over resumes. Tools may generate custom assessments to measure candidate abilities. This could further accelerate inclusive hiring by focusing on actual potential rather than credentials.

- **Integration with Workforce Planning:** AI in recruitment will merge with broader HR analytics. For example, algorithms may predict future skill gaps and recommend recruiting strategies (or even upskilling existing employees) as part of succession planning.

- **Enhanced Candidate Insights:** Recruiting AI will increasingly analyze diverse data (e.g. video interviews, portfolio projects) to give holistic candidate profiles. Interview platforms may use computer vision and sentiment analysis more robustly, while ensuring ethical guardrails.

- **Responsible AI and Regulation:** We foresee stronger regulations (e.g. AI Act) shaping recruitment AI. Firms will need standardized audits for bias. Best practices will include AI "playgrounds" for safe experimentation, ongoing training for recruiters on AI tools and explicit accountability for AI-driven decisions.

- **Hybrid Human-AI Teams:** The role of the recruiter will continue to evolve. Analysts predict that in the next 5 years, recruiters will spend more time on high-touch activities (employer branding, relationship-building) and less on screening, trusting AI for early stages. The ideal model is synergy: AI handles scale and data, humans provide judgment and empathy.

These developments suggest that AI will not simply automate today's processes, but **transform the skillset and strategy** of talent acquisition. Organizations that "AI-enable" thoughtfully – combining technology with human expertise – will reap the efficiency and quality benefits, while also preparing for new regulatory and workforce realities.

10. Discussion

Our synthesis confirms that AI-driven recruitment can substantially boost efficiency. Across multiple sources, common themes emerge: **time savings** and **process standardization** are the primary gains. Recruiters consistently report that automating scheduling and screening is freeing up hours (often 50–70% of manual workload) for more strategic tasks. The evidence from case studies corroborates these reports: companies like Unilever and IBM achieved dramatic cuts in hiring cycle time and costs.

AI's impact on *quality-of-hire* is also promising. By leveraging data patterns, AI identifies high-fit candidates, which translates to better interview performance and retention. Our review found multiple accounts of improved hire outcomes: for example, AI-screened candidates succeeded in final interviews far more often than traditionally selected ones. Similarly, recruiters' expectation that AI will enhance quality-of-hire was widespread (61% of respondents in one survey).

However, realizing these benefits depends on addressing challenges. Our findings emphasize the necessity of transparency and human oversight. Studies warn that recruiters may distrust "black box" systems or fear deskilling if AI replaces too many tasks. Therefore, best practice is to adopt AI in phases, validate its outputs with human review, and continuously monitor for bias. For example, incorporating diverse resume training sets and audit logs can help mitigate algorithmic discrimination. Organizationally, the shift to AI requires change management: as one source notes, organizations should encourage *"AI self-enablement"*—training HR teams to use AI effectively.

From a theoretical standpoint, our review bridges resource-based and technology acceptance perspectives. AI tools, as strategic resources, can drive firm performance (RBV); yet, their adoption also hinges on perceived usefulness (TAM/UTAUT) and user trust. By confirming these lens in the context of recruitment, our analysis contributes to a more integrated understanding of AI in HR.

11. Theoretical Contributions

This study offers several contributions to theory. First, it extends **Resource-Based View (RBV)** and **Dynamic Capabilities Theory** to talent acquisition. By classifying AI technologies as unique organizational capabilities, we show how they can create sustainable hiring advantages (faster fills, better talent pipelines) that align with firm strategy. This builds on prior claims (Tambe, 2014; Chamorro-Premuzic et al., 2019) about AI as strategic HR resource.

Second, we incorporate **Technology Acceptance (UTAUT)** insights into the recruitment domain. The finding that recruiters value AI's efficiency gains (performance expectancy) above other factors mirrors TAM research in other fields. The role of *experience and training* as enablers (as indicated by LinkedIn's emphasis on recruiter AI skills) also aligns with TAM's emphasis on user readiness. In highlighting both organizational (RBV) and individual (TAM) factors, our framework provides a multi-level theory of AI adoption in HR.

Finally, this paper contributes empirically by quantifying impacts across multiple dimensions and synthesizing fragmented literature. The conceptual model (Figure 1) can serve as a foundation for future testing, and the identified impact metrics (time, cost, quality, engagement, diversity) can guide empirical research. We also identify gaps – for instance, the need for more rigorous measures of *quality-of-hire* – which point to future scholarly inquiry.

12. Conclusion

AI-driven recruitment is rapidly maturing from a niche experiment to a mainstream practice. This analysis shows that when used appropriately, AI tools significantly enhance hiring efficiency by **reducing time-to-hire and cost-per-hire, while maintaining or improving quality-of-hire**. Organizations leveraging AI (from resume parsers to video interviews) report dramatic throughput gains. However, these benefits come with responsibilities: mitigating bias, respecting candidate privacy and keeping a "human in the loop" are essential.

In practice, successful AI implementation means using algorithms to streamline routine tasks and data analysis, while preserving the human touch for final decisions and candidate experience. A balanced approach – as advocated by thought leaders (e.g. Glen Cathey of Randstad) – is to allow AI to *"handle routine tasks"* and augment recruiters' judgment. Companies that embrace this collaborative model are poised to attract talent more quickly and consistently, giving them a competitive edge in fast-moving labor markets.

In conclusion, AI-driven recruitment holds great promise for efficiency gains in hiring. This study's comprehensive review suggests that with careful design and governance, organizations can use AI not only to speed up hiring, but to make it smarter, fairer and more strategic.

Acknowledgement

The author, **S. Samuel Glinton**, expresses sincere gratitude to Dr. V. Raghuraman, Dr. Potula Srinivas Rao, Dr. N. Nirmala Devi, Prof. Shiny S., Johnsi S., and Dr. Deepa Rajesh for their invaluable guidance, continuous support, and scholarly insights throughout the course of this research. Their constructive feedback, academic expertise and encouragement have been instrumental in shaping the conceptual framework and enhancing the overall quality of this study. The author acknowledges their significant contribution, which has greatly influenced the successful completion of this research work..

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P07 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Driving Growth: MSME Contributions to the Indian Economic Engine

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Abstract: *This research paper examines the substantial contribution of Micro, Small, and Medium Enterprises (MSMEs) to the Indian economy. Micro, Small, and Medium Enterprises (MSMEs) are of paramount importance in facilitating and promoting economic expansion, generating employment opportunities, and mitigating poverty. The objective of this article is to conduct an analysis of the contributions and obstacles encountered by micro, small, and medium enterprises (MSMEs), along with an examination of the government's efforts to facilitate their growth and progress. This study illuminates the significance of fostering the Micro, Small, and Medium Enterprises (MSMEs) sector in India for the purpose of achieving sustainable economic development.*

Keywords: *MSMEs Employments; GDP; Growth; Economy; Innovation.*

1. INTRODUCTION

The MSME sector in India has emerged as a vibrant and dynamic segment of the economy. It comprises a vast number of enterprises, ranging from micro-enterprises to small and medium-sized enterprises. These enterprises are involved in various sectors, including manufacturing, services, and trade. The objective of this research article is to highlight the pivotal role that MSMEs play in the Indian economy.

The Micro, Small, and Medium Enterprises (MSME) sector plays a substantial role in the manufacturing output, employment, and exports of the country. It is recognised for its contribution to the greatest employment growth rate and its significant share in industrial production and exports. Small businesses possess distinct advantages stemming from their size. They exhibit a relatively high labour-capital ratio, necessitate a shorter gestation period, target smaller markets, require lower investments, promote a fairer distribution of national income, enable the efficient utilisation of underutilised capital and skills, and foster the development of industrial entrepreneurship. The micro, small, and medium enterprises (MSME) sector in India has significant heterogeneity with respect to enterprise size, product and service diversity, and technological sophistication. The presence of ancillary units in conjunction with large industries serves as a complementary factor, making a significant contribution to the overall socioeconomic growth of the country. A recent revision of the MSME Definition was decided by the Government of India on 01.06.2020. In the case of medium enterprises, the investment will be Rs. 50 crore and the turnover will be Rs. 250 crore (PIB 1).

2. Contributions of MSMEs to Indian Economy

Micro, Small, and Medium Enterprises (MSMEs) have made significant contributions to the Indian economy across multiple dimensions, including employment generation, innovation and entrepreneurship, and gross domestic product (GDP) growth. As per the Ministry of Statistics and

Programme Implementation, the gross value added (GVA) of micro, small, and medium enterprises (MSMEs) constitutes a certain percentage of India's gross domestic product (GDP).

MSMEs play a significant role in facilitating employment generation within the Indian economy. These initiatives offer prospects for self-employment and contribute to job creation, particularly in rural and semi-urban regions, encompassing a substantial proportion of the population. The adaptability and capacity for expansion exhibited by micro, small, and medium enterprises (MSMEs) render them highly suitable for accommodating the increasing labour pool inside the nation.

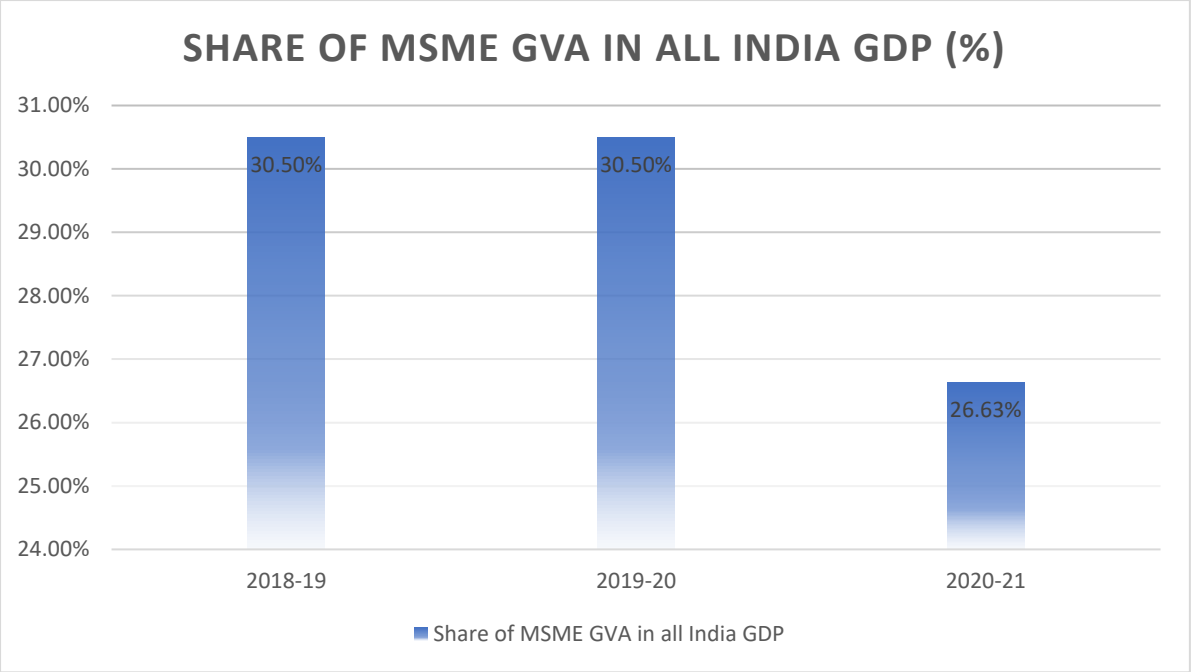

Figure 3 Share of MSME GVA in all India GDP

Source: https://pib.gov.in

Based on the findings of the National Sample Survey (NSS) 73rd round conducted in the fiscal year 2015-2016, it has been determined that the Micro, Small and Medium Enterprises (MSME) sector has generated a total of 11.10 crore employment opportunities. These job opportunities are distributed across various sectors, with 360.41 lakh jobs in manufacturing, 0.07 jobs in non-captive power generation and transmission, 387.18 lakh jobs in trade, and 362.82 lakh jobs in other services.

Table 1 Job created by MSMEs

Broad Activity Category	**Employment (in lakh)**			**Share (%)**
	Rural	Urban	Total	
Manufacturing	186.56	173.86	360.41	32
Electricity*	0.06	0.02	0.07	0
Trade	160.64	226.54	387.87	35
Other Services	150.53	211.69	362.22	33
All	497.78	612.10	1109.89	100

* Non-captive electricity generation and transmission

Source: MSME annual report 2022-23

The Micro, Small, and Medium Enterprises (MSME) sector plays a substantial role in the overall Gross Domestic Product (GDP) of India. These firms provide significant contributions to industrial production, export revenue, and general economic expansion. Micro, Small, and Medium Enterprises (MSMEs) are of paramount importance in facilitating the diversification of the industrial base and fostering inclusive growth.

Micro, Small, and Medium Enterprises (MSMEs) serve as catalysts for fostering innovation and entrepreneurial activities within the Indian context. The organisation cultivates an environment that promotes innovation and exploration, which in turn propels progress in technology and the creation of new products. Micro, Small, and Medium firms (MSMEs) frequently function as a fertile environment for the emergence of future large-scale firms, hence fostering a dynamic ecosystem conducive to economic expansion.

A considerable proportion of Micro, Small, and Medium Enterprises (MSMEs) participate in export-oriented endeavours, hence making a substantial contribution to India's foreign exchange profits. They engage in the production of goods and services that exhibit competitiveness in global markets, thereby contributing to the expansion of the country's export portfolio. According to the Directorate General of Commercial Intelligence & Statistics, the proportion of exports of MSME designated products in the overall exports of India was 49.4% in the year 2020-21 and 45.0% in the year 2021-22. (PIB, Contribution of MSMEs to GDP)

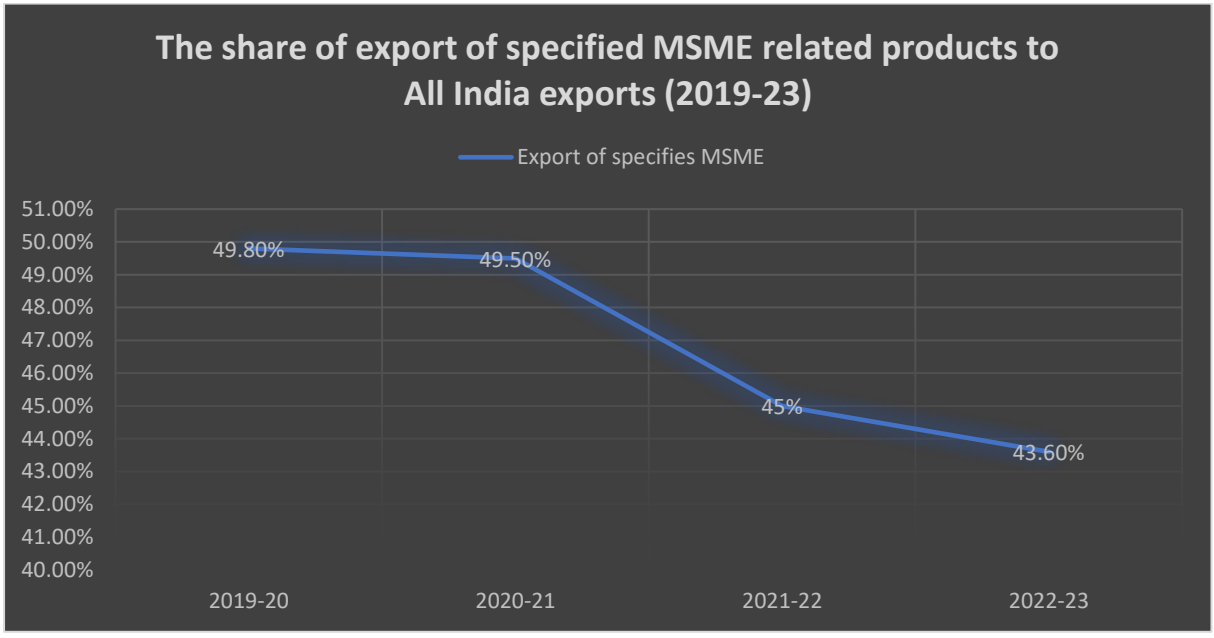

Figure 4 The share of export of specified MSME (2019-23)

3. Challenges Faced by MSMEs

Limited access to funding is a significant obstacle encountered by micro, small, and medium enterprises (MSMEs). Numerous businesses encounter difficulties in obtaining loans as a result of insufficient collateral or a limited credit history. This impedes their capacity for expansion and limits their capacity to invest in contemporary technology, infrastructure, and skilled personnel.

Insufficient infrastructure, encompassing elements such as power supply, transportation, and logistics, is a substantial obstacle for micro, small, and medium enterprises (MSMEs). These limitations result in an escalation of manufacturing expenses, a postponement of delivery timelines, and a restriction on the extent of market penetration. It is imperative to prioritise the resolution of these infrastructural deficiencies in order to bolster the competitiveness of micro, small, and medium enterprises (MSMEs).

Micro, Small, and Medium Enterprises (MSMEs) frequently encounter challenges when it comes to the adoption and integration of novel technologies. The organization's capacity to adopt automation, digitization, and other technological improvements is impeded by constraints in resources and technical expertise. The imperative of narrowing the technology divide is crucial in enhancing productivity, quality, and competitiveness.

4. Government Initiatives to Support MSMEs

Acknowledging the significance of Micro, Small, and Medium Enterprises (MSMEs) in fostering economic growth, the Indian government has implemented a range of programmes aimed at providing support to this sector. The aforementioned items encompass:

The government has implemented a range of initiatives and financial mechanisms aimed at enhancing the accessibility of funding for Micro, Small, and Medium Enterprises (MSMEs). Initiatives such as the Credit Guarantee Fund Scheme and the Micro Units Development and Refinance Agency (MUDRA) have been designed with the objective of facilitating access to loans without the requirement of collateral. These initiatives are intended to foster entrepreneurship and stimulate economic growth.

In order to augment the capacities of Micro, Small, and Medium Enterprises (MSMEs), the government has implemented skill development programmes and training initiatives. These programmes prioritise the dissemination of technical skills, management proficiency, and entrepreneurial knowledge to micro, small, and medium-sized enterprise (MSME) entrepreneurs and their workforce.

The government has implemented strategies aimed at streamlining regulatory procedures and alleviating the compliance obligations placed on micro, small, and medium enterprises (MSMEs). Initiatives like as the Udyog Aadhaar Memorandum and the Single Window System contribute to the facilitation of registration, licencing, and approvals, hence fostering a favourable business environment.

5. Conclusion

Micro, Small, and Medium Enterprises (MSMEs) hold significant importance in the Indian economy as they serve as key drivers of employment generation, contribute to the increase of Gross Domestic Product (GDP), and facilitate the advancement of innovation. Nevertheless, they encounter numerous obstacles that necessitate resolution. By means of governmental initiatives and policy support, it is plausible to enable Micro, Small, and Medium Enterprises (MSMEs) to surmount these obstacles and make a more substantial contribution to the economic development of India. The cultivation of the micro, small, and medium enterprise (MSME) sector is of paramount importance in attaining sustainable and inclusive economic expansion within the nation.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
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DOIs:10.2015/IJIRMF/ICRI-2026-P08 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Rights and Social Security of GIG Workers in India: Emerging Legal Frameworks, Policy Developments and Global Perspectives (2019–2026)

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ABSTRACT: *The gig economy has played a vital role in in India's labour market structure which changes the cultural shift in labour market operation supported by digital platforms, artificial intelligence and innovation in fintech categories. Despite operating over 12 million workers in gig economy in 2025 – it's projected estimated to reach 23.5 million by 2029-30 - but still they are excluded from the rights and social security protections available for conventional workers. This study investigates the deprivation of rights for the gig workers and gap in social security benefits challenges for gig workers in India, by incorporating legislative actions and development of policy frameworks up to April 2026. The approaches of this study by using descriptive and analytical secondary research design, the study analyses Fair work Indian Platform Rating (2019-2024), it traces the evolution of regulation bring by governments to address these issues by centre and state levels, and touches the valuable insights from international regulatory models it covers the European Unions' Platform Work Directive (2024), Singapore's Platform Workers Act (2024), and the United Kingdom's Employment Rights Act (2025). The study presents with a conceptual framework and finds that India's Four Labour Code constitutes a landmark development, three out of four of which still excludes gig workers, platform regulation regarding voluntary fairness standards still determinately inadequate. The study concluded that regulated discussions, and witness-based policy recommendations for both the government and platform-based companies.*

Keywords: *Gig workers, rights, social security, independent contractor, platform economy, minimum wages, living wages, Labour Codes 2025, welfare board, algorithmic management.*

1. INTRODUCTION

The world is now experiencing the unique transformation in digital; India has steady entered the fourth Industrial Revolution. Digital economy breaks down the geographical barriers for enterprises, facilitating organization and individuals to form an idea and implement the novel business models at large scale where the traditional business model fails. Industrial Revolution 4.0, portrayed by mobile

connectivity, cloud computing, smart link devices, smart factories, and mass customization, has change the core things how businesses to hire the talent, deploy them and compensate for them. Fintech based solutions, payment based on using blockchain systems, most significantly real time payment services for the workers, and artificial intelligence-oriented labour management have speed up the drift of labour from permanent payment system into contingent, task-based engagement – quietly known as the 'gig economy'

The gig economy refers to a commercial arrangement take place insight the organisation with the independent contractors for a short period or task-based or task-specific work activities, instead of full time or permanent employment. Unlike a conventional employment, gig workers are collecting partners rather than worker, whereas in traditional employment principal – agent relationships exist between employer and employee deliberate with rights, benefits and social protection upon workers. In gig economy no such formal relationship has existed, on the other hand gig workers fails to get benefits like sick leave, retirement benefits, no minimum or floor wages, provident fund, or state aided insurance through employment. Most critically, gig workers possess minimal or no job security.

India's gig economy workforce, account of 7.7 million in 2020-21 according to NITI Aayog report 2022, its projection will go up to 23.5 million by 2029-30, which pocket for 6.7 percent of the non-agricultural workforce which is very good sign for Indian economy report by economic survey 2025-26. This shows the clear sign it can pull off some of the areas of employment like ridesharing, food and grocery delivery, home services, freelance professional work, and graphic design, among other sectors. Despite this economic significance, gig and platform workers keep on face systematic deprivation of rights or exploitation, wage theft, illegal termination, mental and physical stress, and unfair labour practices, largely because the regulatory framework governing their employment has remained inadequate until recently.

Problem statement the main issue this paper talks about is the ongoing gap between how important gig workers are to the economy and how they are mostly left out of the rights and social security benefits that traditional workers in India get from labour law. Even after the important announcement of India's Four Labour Codes on 21 November 2025, which was the biggest change to labour law in India since Independence, three out of the four codes still do not include gig and platform workers in their protections. Data from Fair Work India from 2019 to 2024 shows that the commitment of platforms to fair practices is still very poor. While there was an increase in state-level welfare laws in 2025, they are inconsistent, mostly not put into action in many areas, and are not designed to meet the needs of a mostly migrant workforce. In light of this situation, there is a crucial need for a thorough, research-driven review of the rights and social security situation for gig workers in India, considering experiences from around the world. This study aims to fill that gap.

2. REVIEW OF LITERATURE

A thorough examination of available research both in India and around the world was conducted to understand the changing situation regarding rights and social safety for gig workers in India. This examination includes studies reviewed by experts, reports from organizations, legal evaluations, and policy papers released from 2016 to 2026.

East Asia Forum (2026) This research shows that India's gig economy is expanding quicker than the rules designed to protect it. Among the Four Labour Codes announced in November 2025, only the Code on Social Security officially acknowledges gig workers. The preliminary national rules published in January 2026 state that to qualify for social security benefits, a worker must be engaged for at least 90 days with one company each year (or 120 days with various companies)—a requirement that critics believe unfairly excludes migrant and those who work on several platforms.

Ray and John (2025) This research looks at how gig and platform workers in India organize and use political methods in the context of digital capitalism. The writers explore how unions for gig

workers used political elections and social activism to advocate for laws that protect them, comparing this to past efforts in Maharashtra, Kerala, and Tamil Nadu related to welfare boards. The research suggests that working together as a group, more than just good intentions from lawmakers, has been the main factor leading to welfare legislation at the state level.

Fair work India (2024) This is the seventh yearly report from the Fairwork India team (CITAPP, IIIT-Bangalore, together with the Oxford Internet Institute) that reviews eleven platforms based on five standards: fair pay, fair working conditions, fair agreements, fair treatment by management, and fair representation. No platform received a score higher than 6 out of 10. Only BigBasket and Urban Company reached the basic minimum wage level. None of the platforms provided a local living wage after expenses were taken into account. Ola, Porter, and Uber received a score of zero for all five standards.

Karandlaje, Ministry of Labour & Employment (2024) This report from the government looks at how the Code on Social Security, 2020 can be applied to the gig economy in India. It focuses on parts of the code that deal with coverage for life and disability, accident insurance, health and maternity support, and benefits for old age. It points out that by the middle of 2025, less than 340,000 out of 12 million gig workers in India had signed up for the national worker registration system, highlighting a big gap in how well these measures are being put into action.

Radhakrishnan and Singha Roy (2023) In their qualitative research on gig economy workers in Bengaluru who use ride-hailing services, the writers discover that even though these workers appreciate independence and flexible hours, most of them end up working between 10 to 14 hours a day just to make enough money to cover basic living expenses in the area. This long working hours result in considerable mental and physical pressure. The research suggests that making benefits transferable and ensuring a minimum pay are important policies that should be put in place.

NITI Aayog (2022) This important policy report finds that there were 7. 7 million gig workers in 2020-21, and it estimates that this number will rise to 23. 5 million by 2029-30. About 47 percent of gig jobs require a medium skill level, 22 percent require a high skill level, and 31 percent are low-skilled jobs, with the low-skilled workers being the most at risk of being taken advantage of. The report suggests that gig work should be made more official, that social security benefits should be included, that skill training programs should be available, and that financial opportunities for platform workers should be improved.

Todoli-Signes (2022) This global study suggests that categorizing workers strictly as employees or independent contractors does not fit the real conditions of platform jobs. It recommends introducing a new group called ‘dependent contractors’ who would have some rights and protections that lie between the two existing categories. This approach has been later accepted in various places, such as the United Kingdom and the EU Platform Work Directive for 2024.

Heeks (2021) Looking into work on digital platforms in the Global South, this research suggests that platform capitalism makes existing job market inequalities worse. The research points out that controlling algorithms, unclear rating systems, and absence of group negotiations are major ways workers face exploitation in nations that are still developing. It also proposes solutions like transparent algorithms, rights for workers regarding their data, and governance models that involve multiple stakeholders.

Countouris and De Stefano (2021) This study, requested by the ILO, claims that gig workers around the world should have basic labor rights protections no matter what their job status is. It suggests creating a new ILO policy that would set essential rights for platform workers, such as a minimum income guarantee, workplace safety, and the ability to form groups or unions.

Riley (2020) This research shows that gig workers ought to have access to fundamental social safety net benefits similar to what regular employees have, such as paid sick days, coverage for injuries, and contributions to a retirement fund. The writer points out that many regulations tend to concentrate mainly on protecting consumers and overlook the needs of workers. They suggest creating a program based on the protections available to 'Small Business Workers' as a practical middle-ground solution.

Prassl and Risak (2016) This important legal study compares different systems and suggests a new idea about what an employer means in the platform economy. It claims that various parties—such as platforms, clients, and aggregators—play employer roles for gig workers at the same time, and that labour laws should make all these parties responsible. This idea of multiple employers forms the basis for asking platforms to help fund social security, as found in India's Four Labour Codes.

Research gap the earlier discussion highlights three key trends in the current research. First, there is a strong agreement among scholars that the simple division between employees and contractors does not work well for gig workers and needs to be changed. Second, the research often points out that platform capitalism and algorithm-based management are ways that companies exploit workers, and that voluntary actions taken by companies haven't solved these issues. Third, while various government reports and new state laws are noted separately in the research, no study has combined the enforcement of the new Four Labour Codes after November 2025, the fast development of state laws for gig worker welfare, and international regulatory trends into one comprehensive analysis. This study fills that gap by offering a complete and current overview of the rights and social security for gig workers in India up to April 2026, based on a new conceptual approach and compared to the best global regulations.

3. OBJECTIVES

i. To explore the challenges gig workers encounter when trying to assert their rights within the current Indian legal system.

ii. To study the difficulties related to social security that gig workers in India face and the responses from both central and state governments (2023–2026).

iii. To provide a current evaluation of how well platforms are following gig worker rights by utilizing Fairwork India Rating information (2019–2024).

iv. To gather insights from regulations in other countries and suggest policy recommendations for India based on evidence.

4. CONCEPTUAL FRAMEWORK

The framework used in this research combines different theories to grasp the complex challenges faced by gig workers and the necessary rules to help them (refer to Figure 1). It places the gig economy within the larger picture of the Fourth Industrial Revolution and platform capitalism, where digital platforms manage and earn from labor without taking on the typical responsibilities of an employer.

This framework highlights three connected areas of focus: (i) the structural area, which looks at the technological and economic reasons for the growth of gig work; (ii) the rights and protection area, which identifies the gap between workers' legal rights and their real-life experiences; and (iii) the regulatory and governance area, which assesses laws at different levels—national, regional, and global—and their success in addressing the shortcomings in workers' rights.

The Capability Approach by Amartya Sen from 1999 serves as the guiding principle of this framework. According to Sen, development—and labor regulations—should not only be measured by income but by the actual freedoms and abilities people can use. For gig workers, this approach means that rules should be judged on whether they allow workers to have fair pay, health benefits, the freedom to join groups, and decent working conditions—not just whether they are officially recognized as

workers. The International Labour Organization's Decent Work Agenda supports this goal through four key areas—job creation, workers' rights, social safety, and communication among groups—which are examined in the context of India's gig economy throughout this paper.

The framework also includes a feedback system: better policy results can change the gig economy itself, impacting how platforms operate, the negotiating power of workers, and the overall regulations. This active element sets the framework apart from unchanging descriptive models and shows how quickly gig worker regulations are changing in India.

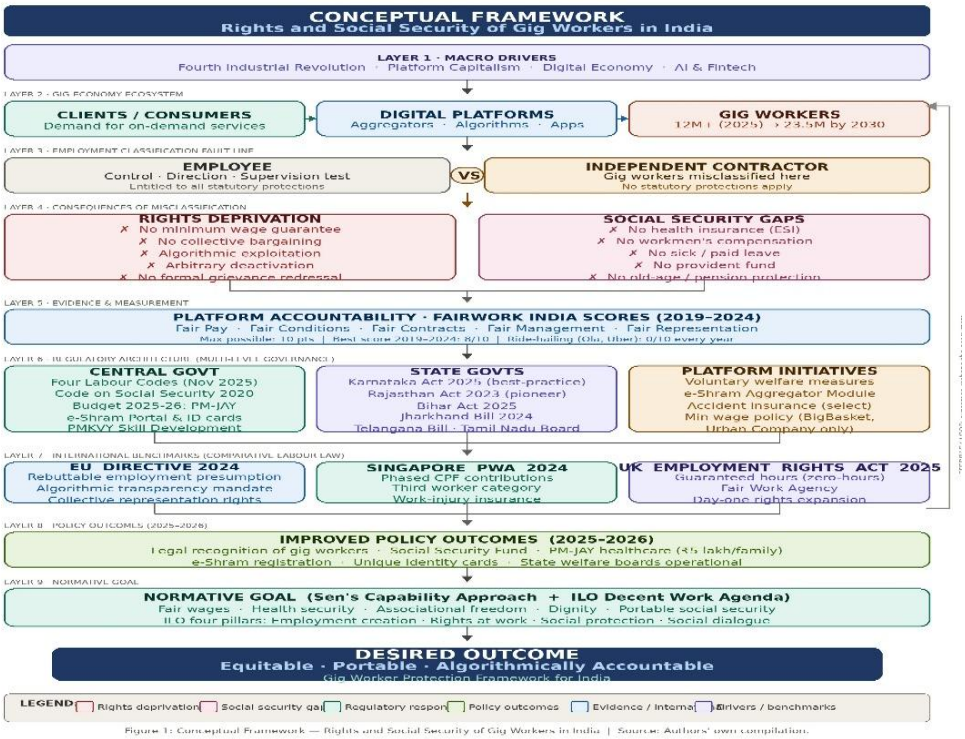

Figure 1: Conceptual Framework — Rights and Social Security of Gig Workers in India | Source: Authors' own compilation.

Figure 1: Conceptual Framework

Table 1: *Conceptual Framework: Analytical Dimensions, Variables, and Theoretical Anchors*

Analytical dimension	Key variables / indicators	Theoretical anchors
Gig economy ecosystem	Digital platforms, aggregators, consumers, gig workers; task-based engagement; real-time fintech payments	Fourth Industrial Revolution; Platform Capitalism (Srnicek, 2017)
Employment classification	Employee vs. independent contractor dichotomy; control–direction–supervision test; absence of formal appointment letter	Misclassification theory; ILO Employment Relationship Recommendation No. 198 (2006)
Rights deprivation	Absence of minimum wages; denial of collective bargaining; arbitrary deactivation; algorithmic management; job insecurity	ILO Decent Work Agenda; Sen's Capability Approach (1999)

Social security gaps	Absence of health insurance (ESI), workmen's compensation, sick leave, maternity benefits, provident fund and old-age protection	Code on Social Security, 2020; Bismarckian welfare model adapted for informal workers
Platform accountability	Fairwork India scores 2019–2024; aggregator welfare fund contributions (1–2% turnover); algorithmic transparency provisions	Corporate social responsibility; Stakeholder theory (Freeman, 1984)
Regulatory architecture	Four Labour Codes (Nov 2025); state welfare boards (Rajasthan, Karnataka, Bihar, Jharkhand, Tamil Nadu, Telangana); e-Shram portal	Multi-level governance theory; Regulatory gap theory
International benchmarks	EU Platform Work Directive (2024); Singapore Platform Workers Act (2024); UK Employment Rights Act (2025)	Comparative labour law; Convergence theory
Policy outcomes (2025–2026)	Legal recognition of gig workers; Social Security Fund; PM-JAY healthcare; identity cards; state welfare boards operational	Welfare state theory; Evidence-based policymaking
Normative goal	Fair wages, health security, associational freedom, dignity, and portable social security for all gig workers	Sen's Capability Approach; ILO Decent Work Agenda — four pillars

Source: *Authors' own compilation based on review of literature.*

5. METHODOLOGY

This research uses a descriptive and analytical design, focusing only on secondary data sources. This choice is intentional and fits the goals of the study: it aims to outline current laws and policies, and for this purpose, using secondary data—taken from trusted government bodies, institutions, and research sources—is the best approach. While gathering primary data can be useful for understanding personal experiences of workers, it wouldn't provide the broad, long-term, and legal insights that the research questions require.

The information was collected from: (i) government documents and official announcements from the Ministry of Labour and Employment, NITI Aayog, the Economic Survey 2025–26, the Press Information Bureau, and various state government announcements; (ii) reports from parliamentary committees and legislative documents related to the Four Labour Codes, the Code on Social Security (2020), and state laws for gig workers (Rajasthan 2023, Karnataka 2025, Bihar 2025, Jharkhand 2024, Telangana 2025); (iii) yearly Fairwork India Rating Reports (2019–2024) created by CITAPP, IIIT-Bangalore, and the Oxford Internet Institute; (iv) academic articles that have been peer-reviewed, obtained from Scopus, Web of Science, and Google Scholar; and (v) legal resources like PRS India and Lexology for insights into legislation. Information about developments in 2025 and 2026 was gathered from official governmental announcements and credible journalistic and institutional reports up to April 2026.

6. PLATFORM COMPLIANCE WITH GIG WORKER RIGHTS: FAIRWORK INDIA RATINGS (2019–2024)

The Fairwork India Platform Ratings between 2019 and 2024 are shown in Table 2. Scores are given out of a possible 10 points based on five principles: fair pay, fair conditions, fair contracts, fair management, and fair representation. The evaluation of each principle is based on two sub-criteria, each worth one point, with the second point granted only when the first has been met. Within each year, platforms are rated in descending order of their scores.

Table 2: *Fairwork India Platform Scores, Ranked by Year (2019–2024)*

Platform	2019	2020	2021	2022	2023	2024
BigBasket	**5**	2	4	**6**	**6**	**6**
Urban Company	4	**8**	**5**	**7**	**5**	**6**
Swiggy	4	1	4	**5**	**5**	**6**
Zomato	4	1	3	4	**5**	**6**
Flipkart / Ekart	**7**	**7**	**7**	**5**	3	1
Zepto	—	—	—	2	4	4
Amazon / ATS	—	2	1	0	2	2
BluSmart	—	—	—	—	**5**	**5**
Dunzo	**5**	4	1	0	1	—
Housejoy / UrbanClap	4	2	—	—	—	—
Rapido	3	—	—	—	—	—
Grofers	—	4	—	—	—	—
PharmEasy	—	—	1	—	—	—
Foodpanda / Uber Eats	2	—	—	—	—	—
Porter	—	—	0	1	0	0
Ola	2	2	0	0	0	0
Uber / Uber Eats	3	1	0	0	1	0

Colour key: ■ 7–8 Excellent ■ 5–6 Good ■ 3–4 Fair ■ 1–2 Poor ■ 0 No points ■ — Not assessed

Source: *Fairwork India Reports (2019–2024). Available at: https://fair.work/en/ratings/india/* | *Note: Score 0 = platform assessed but earned no points across any principle.*

An examination of the Fairwork data expose a few significant patterns directly addressing. BigBasket, Swiggy, Urban Company, and Zomato all achieved the joint highest score in 2024, with

each receiving no more than 6 out of 10 points. Notably, Uber, Porter, and Ola all received zero, indicating they did not satisfy even the basic criteria for any of the five fairness concepts. Only Urban Company and BigBasket supplied proof that their minimum wage rules guarantee that workers are paid at least the hourly minimum salary in their region following the deduction of work-related expenses. A vital issue is that none of the platforms attained the threshold for a local living salary in 2024.

In 2020, Urban Company received the highest score ever recorded in this data series, 8 out of 10, but no other platform has come close to this standard since. The decline of Flipkart from 7 in 2021 to 1 in 2024 indicates that platform labour standards are not improving over time, which is particularly concerning given the general growth of the gig economy over this period. Particularly concerning is the ride-hailing platforms' (Ola, Uber) continuous inability to get any points over the six-year period (2019–2024), since this business employs the greatest percentage of India's gig workforce by volume. Taken together, the Fairwork data backs the idea that voluntary business compliance to fair labor norms is still woefully inadequate, therefore directly addressing RQ3 and emphasizing the need of enforceable legislation.

7. PROBLEMS FACED BY GIG WORKERS IN CLAIMING THEIR RIGHTS

This section addresses by examining the principal categories of rights deprivation experienced by gig workers in India.

7.1 Absence of Minimum Wage Guarantee

Unlike regular workers, who are safeguarded by the Minimum Wages Act of 1948 (now integrated into the Code on Wages, 2019), gig workers in India are compensated per job completed and often not afforded minimum wage protections across several states. Since businesses see these employees as independent contractors, they bear no legal obligation to pay them at least the legally mandated minimum pay. Fairwork India (2019–2024) data indicates that just a small number of sites voluntarily adhere to minimum wage requirements: Out of the eleven platforms surveyed in 2024, only BigBasket and Urban Company did. The Code on Wages, 2019, which went into effect on November 21, 2025, offers more chances for workers in regular jobs but still leaves gig workers without pay protection unless they are reclassified as employees. According to India’s Economic Survey 2025–26, there is a proposal to change from minimum pay to wages depending on the local cost of living; Still, this strategy has not yet expressly included gig workers.

7.2 Low Pay and Divergence from Living Wages

Due to structural unemployment, a sizable portion of the Indian workforce is moving from gig work as a supplemental income stream to gig work as their primary source of support. Most gig workers report net monthly earnings of about ₹10,000 after all deductions. Of these, 43% earn less than ₹500 per day (which is ₹15,000 per month). According to the 'Prisoners on Wheels' report for 2025–26, almost 20% of delivery workers toil between 12 and 14 hours per day, while roughly 55% work between 10 and 12 hours. But after paying for platform-related costs like EMIs, car maintenance, and fines, more than a third of them make less than ₹10,000 every month. The skill difference exacerbates this disparity since semi-skilled and unskilled on-demand employees are routinely underpaid while competent gig workers (software engineers, designers) are paid fairly.

7.3 Misclassification and Exclusion from Indian Labour Law

The primary legal problem confronting gig workers is the mistaken classification of their employment status. Whether someone is deemed an employee in Indian labor law is determined by three criteria: control, direction, and supervision. Companies exploit this discrepancy by letting staff set their own hours while employing algorithms to oversee the delivery of services, including ratings, incentives, and payments. This generates a condition akin to conventional employer supervision without incurring the responsibilities associated with it. For the first time ever, the Four Labour Codes, which were unveiled on November 21, 2025, formally distinguish between gig and platform workers. But

among the four codes, only the Code on Social Security provides protections for gig workers; the codes on wages, safety at work, and industrial relations totally exclude them.

7.4 Denial of Collective Bargaining Rights

ILO Conventions 87 and 98 recognize basic workers' rights as the capacity to gather and bargain collectively. Legal restrictions and an absence of adequate organization fundamentally deprive gig workers in India of the ability to assert this right. Since they are regarded as self-employed independent contractors, they are not eligible for safeguards under the Industrial Disputes Act of 1947 or the Industrial Relations Code of 2020. Being categorized as self-employed also jeopardizes gig worker groups of suffering legal problems under competition laws should they seek to coordinate prices. Even with these challenges, research by Ray and John (2025) has shown that gig workers' unions and collectives have grown, which shows a growing capacity for collective action that has benefited laws at the state level.

7.5 Exploitation through Algorithmic Management

The usage of murky algorithmic systems to supervise, evaluate, punish, and dismiss employees is a crucial component of the current gig economy. The algorithms on these platforms determine who receives assignments, determine surge pricing, assign worker ratings, develop incentive programs, and make judgments regarding deactivation, frequently without any human intervention or actual options for employees. Workers who decline jobs or receive negative reviews from clients risk less visibility, lower compensation, or even permanent account suspension. The Karnataka Platform Based Gig Workers Act of 2025 introduced an innovative regulation: gig workers have the explicit right to decline tasks without incurring penalties, a provision absent in other state laws.

7.6 Other Systemic Issues

In addition to the structural problems noted previously, gig workers face a slew of other institutionalized difficulties. One continuous problem is the delayed or inadequate payment of salaries as these platforms have total authority over when and how payments occur. These platforms might also abruptly freeze their accounts, therefore behaving as though they were fired without any due process or chances to react. It is well known that long working hours and pressure to perform cause physical and psychological stress (Radhakrishnan and Singha Roy, 2023). Workers find themselves trapped in low-paying employment when there are no chances for career advancement and skill development. The absence of official mechanisms to address grievances implies that when employees experience difficulties, these are frequently addressed by the same platform management responsible for the problems. Due to continuous monitoring of their whereabouts, performance, and conduct by algorithms, employees also fret over their privacy.

8. PROBLEMS FACED BY GIG WORKERS IN ACCESSING SOCIAL SECURITY

This section addresses (social security dimension) by examining the principal categories of social security deprivation faced by gig workers.

8.1 Absence of Health Insurance and Medical Coverage

Traditional workers covered by the Employees' State Insurance Act of 1948 have access to complete health and medical benefits. But ESI coverage does not apply to gig workers since they are considered as independent contractors. An essential adjustment introduced in the Union Budget for 2025–26: Almost 1 crore gig workers registered on the e-Shram portal will be offered healthcare assistance under the Pradhan Mantri Jan Arogya Yojana (PM-JAY), providing up to ₹5 lakh per family each year for hospital treatments beyond basic care. This is the first time the central government is directly offering gig workers a large healthcare insurance scheme. The complete scheme for rolling this out is yet under development as of April 2026.

8.2 Non-Availability of Workmen's Compensation Insurance

Under the Employees' Compensation Act of 1923, workers who suffer injuries at their workplace are eligible for financial assistance to offset medical expenses, disabilities, and death benefits. But this legislation excludes them because gig labourers are not categorised as permanent employees. If a delivery driver gets into an accident while delivering a package, the company is not legally liable for any costs that arise. The Karnataka Act 2025 and the Telangana Draft Bill 2025 help to address this issue by making companies pay into funds that provide accident insurance and compensation for lost earnings.

8.3 Absence of Sick Leave and Paid Leave

Platform employees lack legal entitlement to paid leave of any type, including paid sick days. This presents gig workers who are ill with a difficult dilemma: either work when they are unwell or lose out on their pay entirely. As was seen during the COVID-19 pandemic, this scenario motivates individuals to work even when they are unwell and presents health hazards for everyone. Though some businesses like BigBasket, Swiggy, Urban Company, Zepto, and Zomato offer some payment for lost income and some minor accident insurance, these benefits are neither dependable nor regarded as legal sick leave rights.

8.4 Absence of Retirement and Old-Age Protection

Regular job employees benefit from the Employees' Provident Fund and the Employees' Pension Scheme, however gig workers do not have any employer contributions for retirement savings. Voluntary pension scheme for informal sector employees providing a monthly pension of ₹3,000 upon reaching 60, but only for those who enroll and make matching contributions. Although the Union Budget for 2025–26 has raised PM-SYM funding by 37 percent, many low-income gig workers still cannot access this program since it is too costly for them.

9. GOVERNMENT INITIATIVES FOR GIG WORKER WELFARE (2023-2026)

This section addresses by tracing the legislative and policy responses of central government, state governments, and platform companies to gig worker welfare needs.

9.1 Central Government Initiatives

The primary legislation intended to safeguard gig workers in India is the Social Security Code of 2020. It formally classifies gig workers and platform workers as distinct forms of labor for the first time and compels businesses running platforms to contribute between 1 and 12 percent of their annual revenues (with a cap of 5 percent of what they owe workers) to a Social Security Fund. This fund is designed to pay for life insurance, accident insurance, healthcare, maternity support, and retirement security among other benefits. As part of combining 29 labor statutes into four key codes, this Code was formalized and went into force on November 21, 2025. The suggested Central Regulations were made public on December 30, 2025, and are anticipated to be completely in effect by April 1, 2026.

Three significant changes were made public in the Union Budget for 2025–26: (i) all gig workers will receive distinctive identification cards; (ii) employees can register on the e-Shram portal, India's national database for informal laborers that had signed up over 30. 58 million people by January 2025; and (iii) the PM-JAY healthcare plan will be expanded to cover roughly one crore gig workers, offering up to ₹5 lakh in annual health benefits per family. First four to sign up were Urban Company, Zomato, Blinkit, and Uncle Delivery as a new Aggregator Module was evaluated to enable platforms to register themselves and their staff on e-Shram. The Budget also raised the PM-SYM budget by 37 percent and increased funding for the Employment Generation Scheme from ₹10,000 crore to ₹20,000 crore.

The proposed Central Rules presented in January 2026 indicate that in order to be eligible for social security benefits, employees would have to have worked for a minimum of 90 days for a single aggregator or 120 days across several platforms. Direct benefits can provide registered e-Shram workers with ₹1,000 every month, ₹2 lakh for accident death insurance (and ₹1 lakh for partial disability), together with access to PM-SYM. The Pradhan Mantri Kaushal Vikas Yojana still provides training courses meant to enhance the abilities of platform and gig workers.

9.2 State Government Initiatives

Sub-national legislative activity has accelerated dramatically in 2025–2026, with multiple states enacting or advancing dedicated gig worker welfare legislation:

- **Karnataka**: The Karnataka Platform Based Gig Workers (Social Security and Welfare) Act, 2025 (effective 30 May 2025) is India's most comprehensive state law. It guarantees benefit mobility, demands worker registration inside 30 days, and sets a Welfare Board financed by a 1–5% transaction cess. Important features are grievance redressal for platforms with 50+ employees, 14 days' notice for contract changes, weekly payments, and the unique right to decline tasks free from deactivation. On November 19, 2025, thorough Rules were published.
- **Rajasthan**: The groundbreaking Rajasthan Platform Based Gig Workers Act 2023 created a Welfare Board and Social Security Fund using aggregator fees. But execution is still on hold as of 2024 because of the absence of subordinate rules, therefore emphasizing a disconnect between legislative intent and implementation.
- **Bihar**: The Rajasthan model is followed by the Bihar Platform Based Gig Workers Act, 2025, which creates a registration mechanism and Welfare Board funded by aggregator donations. Approved by the Cabinet in June 2025, the Jharkhand Platform Based Gig Workers Bill, 2024 calls for the registration of aggregators and employees in addition to a specialized welfare board.
- **Telangana**: Approved by the Cabinet in November 2025, this Bill requires aggregators to register within 45 days and pay a 1-2% welfare charge. For platforms with 100 or more employees, it calls for dispute resolution, demands openness in algorithms, and sets sanctions for non-compliance.
- **Tamil Nadu**: The 2025 Budget declared a special Welfare Board, electric scooter subsidies, accidental insurance for 1.5 lakh employees, and rest lounges in Chennai and Coimbatore. Workers now register under the Unorganised Workers Welfare Board pending tailored legislation.

9.3 Corporate and Platform Initiatives

As indicated by their Fairwork India ratings, a limited number of companies have voluntarily implemented welfare measures beyond legal obligations. Minimum pay rules and accident insurance safeguards have been established by Urban Company and BigBasket. Swiggy, Urban Company, Zepto, and Zomato all offer income loss compensation as well as accident insurance. Upon the debut of the e-Shram Aggregator Module in 2025, Urban Company, Zomato, Blinkit, and Uncle Delivery actively signed up. But as the Fairwork data reveals, with no platform reaching more than 6 out of 10 points, these voluntary efforts clearly fall woefully short of the all-encompassing social security framework that statutory law must ultimately provide.

10. DISCUSSION

10.1 Addressing the Structural Roots of Rights Deprivation and Social Security Deficits

Findings affirm that the employee–contractor dichotomy structural embed gig worker inadequacies. Platforms profit on this to avoid responsibilities and impose control. The "control test" in Indian labour law does not take algorithmic control into consideration. Seen via Sen's Capability Approach, workers lack the "real freedoms" required for a respectable existence. The Decent Work Agenda of the ILO is jeopardized: There are no rights associated with employment; social security is

unreachable, and social communication is hampered. This mirrors pre-existing disparities (Heeks, 2021) and supports the idea that rights ought to be tied to the "fact of work" (Countouris & De Stefano, 2021).

10.2 Addressing the Effectiveness of India's Legislative Responses

Significant developments consist in the recognition of gig workers and the 2025 announcement of the Four Labour Codes. There is one important drawback, though: Only the Social Security Code acknowledges gig employees. Exclusion from the Wages Code, OSH Code, and Industrial Relations Code deprives them of minimum pay, safety regulations, and collective bargaining capability.

The rate of progress varies from state to state. With its rights for rejecting assignments and transparency in algorithms, Karnataka's 2025 Act stands out everywhere. By contrast, Rajasthan's 2023 Act has not progressed as it lacks the required thorough guidelines, illustrating that drafting legislation also calls for adequate administration and employee pressure.

10.3 Addressing platform Compliance and the Limits of Voluntarism

Voluntary compliance is consistently insufficient, as demonstrated by data from Fairwork (2019-2024). Common is regression as seen by Flipkart's fall from a score of 7 to 1. Ola, Porter, and Uber's consistently zero ratings disprove arguments that market rivalry raises quality. The regulatory emphasis on consumer protection has not improved the well-being of workers (Riley, 2020).

10.4 Addressing Lessons from International Regulatory Models

India finds four lessons appearing:

- EU: A employment presumption transferring the onus of proof onto platforms.
- Singapore: Phased social security fund (CPF) contributions model.
- UK: For primary livelihood earners, guaranteed minimum hours or income.
- Global Standard: Mandatory transparency in algorithms.

11. RECOMMENDATIONS AND SUGGESTIONS

11.1 For the Central Government

- **Inclusive Legal Reform:** Amend the labor relations legislation, safety rules, and wage statutes to include gig workers, therefore guaranteeing that everyone receives minimum pay protections free from discrimination.
- **Threshold Reform:** Either lower the number of days required for social security eligibility from 90 to 45 or establish a system whereby payments are determined by the volume of work completed to accommodate employees with seasonal employment or those working across several platforms.
- **Employment Presumption:** Establish a legal presumption that gig workers managed by algorithms (e.g., pricing or ratings) are employees, hence shifting the burden of proof to the firms to show otherwise.
- **National Interoperable Registry:** To guarantee that half of delivery workers, who often move between states, may readily access their benefits, link the e-Shram portal to a central registry.
- **Algorithmic Accountability:** Make firms expose the criteria used in automated decisions and establish mechanisms for human review and appeal of such decisions.

11.2 For State Governments

- **First Action:** Go beyond just planning to swiftly distribute the lesser legislation and start Welfare Boards, along with gathering donations, particularly in Rajasthan.
- **Comparative Legal Systems:** Maharashtra and Gujarat and other states ought to examine the Karnataka 2025 Act, which emphasizes the entitlement to refuse employment and the freedom to move benefits.

- **Cross-State Cooperation:** Make agreements that let welfare benefits be recognised in other states, therefore protecting employees who relocate for employment.

11.3 For Platform Companies

- **Living Wage Policies:** Commit to verified **living wage** standards to address the finding that 1/3 of workers earn <₹10,000/month despite 12-14 hour shifts.
- **Aggregator Registration:** Proactively join the **e-Shram Aggregator Module** to facilitate worker access to PM-JAY and PM-SYM welfare schemes.
- **Transparent Management:** Replace opaque algorithms with contestable systems, providing clear data on task allocation and accessible grievance redressal

11.4 International Comparative Lessons

- **European Union:** India should adopt the rebuttable presumption of employment and the prohibition of sensitive data collection used in the EU.
- **Singapore (Platform Workers Act 2024):** Utilize the phased-in mandatory CPF (social security) contribution model, which allows for gradual implementation without immediate full reclassification.
- **United Kingdom (Employment Rights Act 2025):** Explore guaranteed minimum income or hours for "primary-livelihood" gig workers to stabilize earnings.

12. CONCLUSION

Indian gig workers deal with real problems—no guaranteed minimum wages, no chance to bargain together, and algorithms controlling everything, often to their disadvantage. At the heart of it all is an outdated way of classifying jobs. The old setup, splitting people into “employees” or “contractors,” just doesn’t work when you’re talking about platform companies using algorithms to decide every move. Sen’s Capability Approach cuts right to the chase: the current situation fails gig workers, doesn’t let them live with dignity, even though they keep the digital economy running.

From 2023 to 2026, we’ve seen legal changes like the Four Labour Codes and the growth of the e-Shram registry. Sure, those sound good on paper, but the reality? It’s still not enough. Only one of the four codes formally recognizes gig workers, and there are big gaps in how states put these rules into practice. Strict eligibility requirements make things worse. If you look at Fairwork India’s data between 2019 and 2024, platforms aren’t doing better voluntarily—ride-hailing apps are stuck at a score of zero. Companies just aren’t choosing to improve, so relying on them to do the right thing isn’t working. India needs strong, enforceable laws—not just voluntary promises.

Looking forward, India has options. Other countries have found real fixes: the EU presumes employment, Singapore rolls out phased contributions, and the UK guarantees minimum hours. India doesn’t need to copy them outright—it can adapt these ideas to its federal system. The gig economy brings big job opportunities, but unless India figures out how to manage it and protect workers, it’s just trouble waiting to happen. Moving from “recognition without rights” to a system where protections actually follow workers, and companies are held accountable, will make the digital boom truly inclusive and sustainable. That’s what India needs for its digital future.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P09 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

Fourth World Studies cum Invisible Geo-space in Asia: An analytics on Marginality speaking of the Indian Sundarbans

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Abstract: *In critical sociology, the concepts of the 'Invisible World' or the 'Fourth World' emerged to describe populations that—despite residing within the boundaries of recognized nation-states—remain structurally marginalized. Such multilayered conditions of marginalization are observed in several regions across Asia. A convincing case of this phenomenon is the Sundarbans region of India. Despite its gigantic global ecological significance as a mangrove ecosystem, a vast segment of the Sundarbans' inhabitants remains socially, politically, and economically invisible livelihood. This paper analytically examines the Sundarbans through the theoretical lens of 'Fourth World Studies' and within the broader discourse on marginality; its objective is to understand how environmental vulnerability, administrative remoteness, and socio-cultural dispossession collectively construct an 'invisible Geo-space' within the Indian state. This study also makes a noteworthy input to the broader body of research on Asian passive marginality and coastal rights.*

Key Words: *Invisible Geo-space, Fourth World Studies, Asian Passive Marginality, Indian Sundarbans, Mangrove Ecosystem, Coastal rights.*

1.INTRODUCTION

The impression of the 'Invisible Geo-space' or the 'Fourth World' (Eqeiq 2013, Pp: 3-4) has emerged in influential social science to describe communities that stay behind structurally marginalized despite living within recognized nation-states. Such conditions of layered marginality, where ecological vulnerability, historical neglect, and socioeconomic exclusion converge, are evident in a number of Asian regions (Istrate, Lao, and Sonet 2026). The most striking example of this phenomenon is the Indian Sundarbans, located in the southern part of West Bengal with 102 islands along the dampier-hodges line in north side, touched the Bay of Bengal to southern part, Bhagirathi-hooghly is channelized from west and demarcating by the Harinbhanga river in east from Bangladesh (Mondal 2024). Large portions of the Sundarbans inhabitants carry on to be socially, politically, culturally, and economically marginalized despite the region's global inclusive ecological significance as a mangrove ecosystem and a UNESCO-recognized biosphere (The Sundarbans, n.d.).

Defining the Study Audience

In the realm of social and cultural studies, the notion of the Invisible geo-space (How We See the Invisible World, n. d.) and the term 'Fourth World' (Castells 2000) is employed to describe communities that are overlooked, neglected, and marginalized within society. Far from city centers, some groups live on the edges of maps. Their voices slip through cracks in research and policy talks. Across parts of Asia, progress passes them by - held back by deep-rooted barriers in society, money matters, and shifting land conditions (Behera and Nathan 2024). Looking closely at hidden lives matters since understanding grows when we see struggles others ignore. The Sundarbans stand out across India as one example where silence replaces voice. When ideas about exclusion take shape, researchers begin noticing patterns in who gets shut out - economically, socially, politically. Survival there demands constant effort, yet stories from the region rarely appear in talks about progress. Life in the Sundarbans shifts under pressure from both warming climates and sinking shores - layered atop daily money struggles (Ghosh, Bose, and Brahmachari 2018). From this edge, the research draws attention to a hidden layer of existence: the unseen communities forming what some call the Fourth World across parts of Asia. Looking closely at how life unfolds here, the study brings out what residents face every day. Because their stories matter, spotting patterns helps show where support is truly needed. When these insights get shared, they open doors to fairer choices in planning and change. What happens next depends on listening without filtering or skipping details.

The term 'Marginality' (Call 1986; Independent Viewpoint 1984) has gained immense popularity in recent times. But, what is meant by marginality? It is better to admit that the notion of marginality is rather vague. Simply speaking, the term 'Marginality' has close association with those who live on the margin of society. At length, it may be observed that marginalised people are those for whom the society pays no attention. The result is that the marginalised people often become the victims of exploitation from all corners. With the passage of time, many critics and researchers have been attempting to explore multiple dimensions of marginality. Attempts should also be made to provide with various definitions of marginality. The term 'Marginality' refers to the position of dissident intellectuals and social groups like the women, the Lesbians, the Gays, the blacks, the minorities, the physically challenged people (Irvine 2002), the Dalits who see themselves at a remove from the normative assumptions and oppressive power-structures of mainstream society (Ingole 2020). The term 'Marginality' (Gurung and Kollmair 2005) also suggests a negative experience of alienation. The term is used in academic debate and activist politics to suggest a position of advantage from which the dominant society can be critiqued and disrupted. Here, the difficulties are that all such individuals or groups have not the resources to speak from the margin. Some other definitions of marginality may be dealt with at this juncture. In the year 2003, the International Geographical Union (IGU) defines marginality (Marginalisation, Globalisation, and Regional and Local Response. n. d.) thus, 'Marginality can be defined as the temporary state of having been put aside of living in relative isolation, at the edge of a system (cultural, social, political or economic)...in mind, when one excludes certain domains or phenomena from one's thinking because they do not correspond to the mainstream philosophy'. In his article, 'The Marginal Man: A Study in Personality and Cultural Conflict'. Everett. V. Stonequest observes, 'A marginal person is one who is poised in psychological uncertainty between two (or more) social worlds; one of which is often 'dominant' over the other' (Stonequist 1961).

The Webster Dictionary lists the following definitions of marginality (Bradatan and Craiutu 2012), 'Pertaining to a margin; situated on the border or edge; at the outer limits almost insufficient.(e.g. marginal subsistence written or printed in the margin of a page); marked by contact with two or more different groups, the cultural values or traits of which have not been completely accepted.' In sociology, a 'marginal man' for example, is defined as a person who lives on the margins of two or more groups without feeling identified with either group. In the notable article, 'The Paradox of Marginality', Costica Bradatan and Aurelian Craitu (Bradatan and Craiutu 2012) illustrate, "In addition to these meanings of 'marginality' often used in daily vocabulary, there are also others that are commonly used. In economics, for example, 'marginality' is about selling goods at a price which just equals the additional cost of producing the last unit supplied; or pertaining to goods produced and marketed at margin. 'Marginal' can also be applied to utility to refer to the extra utility or satisfaction derived by a consumer

from the consumption of the last unit of a commodity. Hence, the phenomenon is known as 'marginal revolution'. So, a proper study of marginality must shed light on all or most of its facets. In particular, special attention ought to be paid to explore both the 'positional' elements of marginality (marginality in relation to something else), as well as its 'substantive' aspects. Over all, it is obvious that 'marginality' is a 'relative and dynamic term', requiring a multifaceted and cross-disciplinary approach.' Theoretically, the concepts of marginality derives from the combined influences of Psycho-Analysis, Theories of Ideology and Deconstruction which have altered critics to suppress or subordinated meanings and provide the critical means to elicit these. Marginality also embodies spatial metaphor as does the related distinction between the centre and periphery which owes something to study in cultural geography and post-colonialism (Yeoh 2003). All these perspectives point out that marginalised groups, whether or not in association with textual meanings, reside in suburbs, ghettos on the edge of cities or in the third-world cultures made marginal to the first world (Haynes and Hutchison 2008). In these broader context, Western intellectuals who deem themselves marginal are revealed as centred. Post-colonial critics argue for changing this situation by strategically reversing it. At this juncture, it is important to note that there are different types or multiple layers of marginality that should be explored gradually.

In their illuminating article, 'The Paradox of Marginality', Costica Bradatan and Aurellian Craitu have explored three levels of marginality. In the first level, efforts have been engaged to speak of some books and authors that were lost into the wilderness of the past. Presently, in an altered situation, attempts are made to give due importance on those books and authors that are no longer be treated as marginal. For instance, in the year 1917, T.S. Eliot wrote an essay under the title 'The Metaphysical Poets' (T.S. Eliot on The Metaphysical Poets 1921). Since then, the intellectuals begin to pay attention to the excellence of metaphysical poetry. In the second level, the centre-based paradigms of social sciences and humanities have been challenged. The assumption is that the categories of the centre and the margin are relative. The concept may be changed with the passage of time and circumstances. In the third level, the marginality of idea, research, thought occurs. For instance, to speak of the Gays is of course daring and marginal on the plea that it breaks the social taboo (Navtej Singh Johar vs Union of India Ministry of Law 2018). In their brain-storming article, 'Marginality: Concepts and Their Limitations', Ghana S. Gurung and Michael Kollmair divide marginality into two categories (Paricha 2018). They are 'Societal Marginality' and 'Spatial Marginality'. It has been illustrated, 'Societal Marginality is by and large, reflected on the understanding social conditions of people. The conditions are represented by poor livelihood options (lack of resources, skills and opportunities), reduced or restricted participation in public space, lower sense of community and low self-esteem. Marginalised people are usually discriminated against stigmatised, ignored and often suppressed on the basis of race, gender, age, culture, religion, ethnicity, occupation, education and economy by the mainstream' (Marginalised Minorities in Developing Programming 2010). It is also true at the same time that exploitation leads to societal marginality are child labour, gender inequalities, social exclusion, human rights violations etc. 'Spatial Marginality' has close association with Geography. The term 'Spatial Marginality' denotes those who are living in an isolated place, remote from the mainstream of population. Ghana S Gurung and Michael Kollmair (Gurung and Kollmair 2005) write, 'The dimension of spatial marginality is usually linked to the Geographical remoteness of an area from major economic centres (location), and refers to areas that are difficult to reach(access) in the absence of appropriate infrastructure and therefore isolated from mainstream development.' There are two types of spatial marginality. They are Macro-spatial marginality and Micro-spatial marginality.

There are different modes of marginality other than societal and spatial marginality. Usually, they belong to the domain of thought. Some of such modes of marginality are epistemic marginality, authorial marginality, cultural marginality, geographic marginality. Epistemic marginality denotes the marginality of an idea, concept, theory, methodology (Gatzweiler and Baumuller 2013; Braun and Gatzweiler 2004). Authorial marginality stands for the marginality of an author in relation to the mainstream. Cultural marginality expresses some ideas relating to local culture of research, marginal research programme and agendas. Geographic marginality refers to the peripheral places or cultures and their relationship to the metropolitan centres. Another classic case in point is the marginalisation of

women philosophers in the Western canon of political thought. There is already a considerable literature on this topic, in particular Susan MOkin's (1979) Women in the History of Political Thought and Jean Bethke Elshtai's Public Man, Private Women (Lane, 1981) may be cited as glaring instances in point. Recently, the notion of creative marginality has become extremely popular. The concepts of creative marginality refers to the process through which researchers in academic fields move away from the mainstream and toward the margins of their fields and look forward the margins of other fields that may overlap with and fill in gaps in their fields. This interaction, occurring outside of disciplinary boundaries, promotes intellectual cross-fertilization and it is often the site of innovation.

In the article, 'Marginality and Mattering: Key Issues in Building Community', Nancy K. Schlossberg attempts to link the concepts of marginality and mattering (Harris & Nagle, 2023). Employing the polar themes of marginality and mattering, the narrator brings about the proximity between rich and poor, young and old, male and female. The narrator also raises some fundamental questions like— are we part of things? Do we belong and are we central or marginal? etc. On the basis of the above questions, a conclusion may be drawn. The conclusion is that mattering is an important consideration in regard to the understanding of marginality and its changing state. Some factors are essential to apprehend whether one is marginalised in the real sense. These factors are Attention, Importance, Ego-extension, Dependence and Appreciation. Attention is an important mattering on the plea that it enables oneself to apprehend whether he has any importance at all. Another mattering is of course Importance. With the help of this mattering, one can understand whether anybody cares for his own desire and expectation. Ego-extension refers to the feeling that other people will be proud of our accomplishments or saddened by our failures. Dependence is another important consideration that may make oneself active or passive in his day to daybehaviour and actions. Appreciation is another mattering that provokes oneself to perform his deeds more energetically. Suffice it to say that in the absence of these mattering, one may feel marginalised at any moment and at anywhere irrespective of caste, creed, religion, ranks or status. At this juncture, it should be noted categorically that the level of marginality may vary from time to time and from place to place.

Criticality

Looking into life on the edges of the Sundarbans matters - it shows how tough things really are for those who call this place home. Sure, the place boasts lush scenery and animals of many kinds. Yet life there hides tougher truths behind that beauty. People live scattered on faraway islands. Though cut off, they manage anyway - no steady paths to travel, no clinics nearby, no market within reach, no way to stay in touch easily. These deficiencies profoundly influence life, subtly yet significantly, molding daily practices more by scarcity than by availability (Jamal, Ghosh, Hazarika and Sen 2022). Out here, voices often go unheard when big decisions get made about progress. What stands out most is how money, society and nature tangle in ways that push people to the edges. Storms hit hard every few seasons - flooding fields, washing away houses, wrecking boats of life. Life relies heavily on catching fish, growing crops, or gathering from forests - work that shifts without warning. These struggles repeat, shaped by forces beyond anyone's control. Hard times make life tough here - poverty sticks around, people leave looking for work, chances stay scarce. Not being heard hits hard too; decisions about progress often ignore those actually living in the Sundarbans. National talks seldom carry their voices, their day-to-day struggles missing completely. Looking closely at who gets pushed aside reveals what life really feels like in this shaky corner of the country - it points toward fairer rules, lasting growth, and real help where it's needed most.

2.Statement of the Problem

The fundamental research challenge is the paradox between global ecological appreciation and local socio-economic invisibility or neglect. Though the Sundarbans draws attention worldwide for wildlife and environmental risk, the people living there stay mostly unseen in official conversations about progress. Lives shaped by forests, fishing, or seasonal work - particularly those of women and poor families - rarely make it into dominant narratives on growth. Recognition from afar does little to amplify their realities close up.

Out in the Sundarbans, life carries on quietly despite heavy burdens most never see. Though it holds the title of biggest mangrove forest globally, daily survival here wears down families slowly. Hardship piles up where roads end and boats take over. Cut off by winding waterways and scattered landmasses, help rarely arrives fast enough. Modern schools show up sparsely across the islands. Medical care stays distant for many who need it. Poverty settles deep when opportunity floats just out of reach. Remote corners mean voices go unheard beyond local tides. Cut off like this, getting help from officials feels out of reach for many. On top of that, storms never stay far away for long. When cyclones hit, when rivers swell or creep sideways, houses crack, fields drown, trees fall. Lives hang on farming, nets dipped in water, gathering what woods provide - shaky ground at best. With each storm season, more feel pushed beyond their limits when life pushes people to leave, staying behind stops being an option. Even though these hurdles shape daily existence, voices from Sundarbans villages rarely reach decision rooms or studies (Mondal 2024). What follows is silence where solutions should grow. Unseen, their struggles carry on. So here it begins - the core issue this work looks at isn't just about land or trees, but lives pushed aside quietly. Not only do communities in the Sundarbans face harsh surroundings, they also go unseen by mainstream narratives. Because of how remote these areas are, voices often fade before reaching wider ears. This research turns toward those unheard stories, placing them under a lens shaped by Fourth World thinking. What emerges is not a grand claim, rather a quiet insistence: some people remain off maps yet carry deep knowledge. Their daily survival speaks louder than policy jargon ever could.

3.Objectives of the Study

This research analytically examines the Sundarbans through the theoretical lens of Fourth World Studies and the broader discourse of marginality to understand how environmental fragility, administrative distance and socio-cultural exclusion create an 'invisible geo-space' within the Indian state. In order to achieve this target, it is expected to create awareness about their struggles and motivate the scholars and the policymakers to pay more attention on their needs.

4.Methodology

The research employs a mixed-method qualitative approach. Primary data collected through field-based methods in selected islands of the Indian Sundarbans such as Tushkhali, dhamakhali, Bouthakurani, Jeliakhali, Dhol khali in Sandeshkhali-II Block, Ghoramara in Sagar Blockk, and Garanbose, Birinchi bari-Nafarganj (villages) in Basanti Block.

5.Research Questions

This study on marginality in the Sundarbans tries to understand the social, economic and environmental conditions of the people living in this region. The research questions guide the study and help to focus on the important issues related to the idea of the Invisible World or Fourth World in Asia. Such research questions may be reflected in the following way:

I. What is the role of Forth World marginality in understanding socio-political and administrative invisibility of communities in the Indian Sundarbans?
II. How do the local communities negotiate the means for survival, resilience within the framework of structural marginalization?

6.Understanding Case Literature

a. Case 1: The Hungry Tide

Life unfolds in shifting patterns across the Sundarbans, shaped by Amitav Ghosh's 'The Hungry Tide' (2004) (Ray, R. and Sengupta, S. 2023).

Beauty hides within a landscape that can turn fierce without warning.Tides pull and push daily, reshap ing mudbanks while storms redraw boundaries overnight. This vast mangrove stretch holds uneasy gr ound between survival and loss. Water does not stay still here, nor do lives anchored near it.Out here among tangled roots and silent tides, life hums wild and thick with birdsong, yet days stretch thin for those who call it home. Hardship slips into routines, shaping choices without warning or mercy. Ghosh

moves his figures across this land like shifting weather - each choice they make pressed down by salt, wind, fear. Not merely background noise, the Sundarbans breathes on its own, leaning hard against hopes, bending plans out of shape. People like Piya step carefully through currents both human and tidal, while Kanai watches, caught between worlds. Fokir carries weight no one names - the kind that gathers slowly, then never leaves. Their paths trace deeper lines than story alone could hold, marking loss, labor, rising water.

Out here, where river meets island, the ground never stays the same. Tides shift shapes overnight, redrawing maps without asking. Homes vanish when water rises - no warning, just waves. Rebuilding comes naturally because staying means starting over, again and again. Storms hang like threats in the air, always possible, never far. When salt seeps into soil after floodwaters pass, seeds refuse to grow. Crops fail not from neglect but from nature rewriting the rules. Living here means trusting nothing - not land, not sky, not tomorrow. Out on the water, fishing shapes most lives. Yet danger hides beneath calm surfaces - rivers run deep, unpredictable. Through his story, Amitav Ghosh captures how villagers face such risks without surprise. Life moves forward even when floods rise or nets come up empty. Strength shows not in grand moments but in returning each dawn to fight slow tides and tangled currents. Resilience grows quietly where land meets Wild River.

Out here in the Sundarbans, wild animals make daily survival harder. Known widely for its Royal Bengal Tigers, the area holds real threat - these big cats sometimes hunt people. Those who go into the woods for honey, timber, or fishing face risks each time they step foot inside. Stories in the book reveal moments when tigers strike at locals, showing how close danger always is. Fear runs deep after such events, still the forest gets visited again and again since living without it isn't possible. Waterways hide crocodiles, along with less seen but just as deadly animals. Life here pushes each day against unseen dangers. Not fear alone shapes how villagers act, yet a kind of cautious trust built through years. Nature is neither friend nor enemy, rather something older than words can hold. Living close means watching closely, stepping lightly, breathing slow when shadows shift near shorelines.

The issue of poverty represents a significant challenge encountered by the inhabitants of the Sundarbans in The Hungry Tide. A handful of rupees each week - that's what most folks here live on, pulling nets from the water or tending small plots near the trees. Schooling? Rare. Jobs? Even rarer. Life stays stuck when chances to move ahead barely show up at all. Take Fokir - he rows every morning before sunrise, hands cracked from rope and salt. The Ganga gives him just enough to keep going, nothing more. His world turns around a single boat, worn thin by years of current and need. Out here, knowing every shift in tide and hidden channel means everything. Still, nobody cares about him - school never happened, plus he comes from a group others ignore. In Fokir's story, Ghosh paints daily life in the Sundarbans: poor, yes, but full of quiet pride. Effort fuels each day; roots run deep into the land although help barely ever arrives.

Hard times mark daily life in the Sundarbans, as seen in The Hungry Tide. Week after week, people survive on tiny sums - fishing boats creak under their efforts or crops grow thin between roots. Education slips through fingers like sand. Work outside these routines almost never appears. Stuck is how it feels when doors stay shut without warning. Each dawn finds Fokir already moving, oars cutting dark water, palms split open from lines and brine. From the river, he takes only what keeps breath in his chest - no surplus, no ease. A single boat keeps his days moving, its wood thinned by time, water, and constant use. What matters out here is reading the tides, spotting unseen paths through the water - those things keep him alive. Yet no one sees him clearly - no classroom shaped his youth, nor does society make space for people like him. Through Fokir's eyes, Ghosh shows how life lives itself in the Sundarbans - not rich, yet standing firm without noise. Each morning begins with work that asks much; belonging ties him tight to soil even when support stays far away.

Even with hardships, The Hungry Tide shows how strong the Sundarbans people are. Water nearby has shown them the rhythm of nature, each wave bringing its own lesson. Fokir reads the rivers like old letters sent by the sea, each tide telling its own story. Because he listens so closely, paths others fear become clear under his hand. Beliefs passed down through years shape how they move among trees and currents. Respect grows where life depends on balance, not control. The forest breathes with them, not just around them. Facing struggle head on, the people in Ghosh's stories hold fast to quiet courage.

Not giving up easily, they look ahead with cautious expectation. Rooted deeply in their surroundings, daily life moves without grand claims or promises. Resilience grows quietly here, shaped by tides, soil, and memory.

A place where danger walks barefoot, The Hungry Tide pulls no punches. Lives bend under sudden floods instead of promises. Famine carves the faces of Ghosh's people, their lives measured more by empty stomachs than dreams. Beyond the tree line, tigers wait - felt but never seen - as each year makes living feel lighter. Weather crashes in without warning, bending homes and habits alike. Still, underneath it all pulses another rhythm: stubborn courage, knowledge older than memory, motion despite resistance.This land, feared by some, holds more than risk - it reveals what humans endure, adapt, overcome. Voices like Fokir's rise from silence, brought forward not out of pity but presence. Beauty exists, yes, tangled in mangroves and waterways - though never forget the price paid daily just to walk those paths with head held high.

b. Case 2: Blood Island - An Oral History of the Marichjhapi Massacre

The present novel deals with a story that remains unheard so far. 'Blood Island: An Oral History of the Marichjhapi Massacre' is a novel written by Deep Halder. It was published in the year 2019. Lives disrupted by displacement take shape between its pages. Instead of grand narratives, it leans on what survivors said, moment by fragile moment. Settlers once escaped upheaval in East Pakistan - today's Bangladesh - searching for peace. Their hope led them to the Sundarbans, where survival turned into resistance. What followed was not welcome but violence. Though called a novel, its core beats like recorded memory. Most who arrived were landless, searching not for glory but ground beneath their feet. From interviews stitched together emerges a version of history rarely held up to light. Not triumph, just testimony. Safety, dignity, a quiet life - these brought them to the Sundarbans. A fresh beginning appeared possible among its tangled roots and silent tides. Yet hope quickly gave way to daily battles just to stay alive. Voices rise from the pages, each one carrying pain, grit, strength. What unfolds is more than political harm; it is hunger, loss, stubborn breath in humid dark.

Left behind by nearly everyone, the ones arriving at Marichjhapi lived on the edges of acceptance. Most came from downtrodden groups, carrying scars from past uprooting and grief. Fleeing East Pakistan at one point, after that came months in Indian refugee camps - tight spaces, little there, hardly enough to get by. Yet moving on sheer will alone, they made their way to Marichjhapi, a scrap of earth hidden within the thick mangroves of the Sundarbans. Their aim? To build something stable, finally. Hard work, they thought, would let them raise homes, grow food, open schools, set up market stalls. Trees came down as displaced people put together shelters, turned soil into fields. Fishing nets appeared along the shore, trade began in makeshift clearings - ways to feed those who depended on them. Their persistence stood out, even when everything around was scarce and uncertain. Trouble arrived when officials saw the growing camp not as hope but as defiance.

Hard times marked every day in the Sundarbans. Rivers twisted through clusters of small islands, linked by waterways rising with each tide. When storms hit, everything changed fast - homes washed away, paths vanished overnight. Building shelter meant working nonstop under harsh sun and sudden rains. Salt soaked into the ground so deeply crops barely survived. Each harvest came slower than the last, if it came at all. Water safe to drink came only in small amounts. Floating slowly, boats picked their way among islands, slipping through narrow channels that might erupt with rough water at any moment. Trees crowded together in dense woods, hiding tigers, while crocodiles waited by muddy shores and snakes rested under wet foliage. Life went on anyway - men cast nets at dawn, families turned soil under hot sun, hands gathered roots and bark deep inside tangled woods. What kept them going wasn't luck but something sturdier: quiet willpower showing up each day like tide. Courage here looked less like bravery, more like breathing.

What hurts most in the story is how officials treated those seeking shelter. Back in 1979, leaders said the Marichjhapi camp broke rules, demanding everyone pack up and go. Since folks stayed - having no other place - the state shut everything down. Supplies like rice, clean water, even basic pills never made it through. Ships loaded with aid could not get through. Hunger spread fast - then sickness followed close behind. Older folks and kids passed away without enough meals or treatment nearby. Those who

made it recall splitting tiny bits of bread among kin. Pain lives on in these stories, showing what powerlessness felt like back then.

Out of nowhere, things took a sharp turn once officers showed up to clear the settlers off Marichjhapi. Voices from the pages tell how people got assaulted, shelters torn down, lives lost or broken. Driven from land they'd shaped with relentless effort stood women, men, kids alike. In memories that linger, survivors speak of panic spreading fast when order turned to disorder. Flames swallowed boats. Walls came crashing down. Kin scattered in different directions. Wandering once more, those who fled found no place to stay. One of the grim moments in Sundarbans' past, it reveals lives bent by choices made far away.

Still carrying scars long after everything ended, some people recall what it felt like to go without food or safety. Voices once silenced now speak through recordings on Blood Island, kept alive by choice. Pain lingers, yes - especially around loss and being forced away from home. Yet moments of courage show up quietly between the lines. New beginnings took root far from where things started, often built slowly through daily effort for loved ones. Out of hardship came strength, clear in every tale they shared. Though often overlooked, their voices now find space through Deep Halder's words - each one a mark against silence.

Looking back, Blood Island: An Oral History of the Marichjhapi Massacre tells a strong story about hardship among forgotten people in the Sundarbans. Notable detail - biting wind sliced through thin tent walls, yet terror arrived sharper from guards carrying weapons.Survivors recall mornings without food, yet still lighting fires to cook shared rice in cracked pots. A child's drawing of a boat floats near pages describing gunfire at dawn - simple lines holding heavy silence. After a while, these pieces gather - messy, uneven, much like debris left behind when the wind finally stops. Joy shows up too, thin and careful, hidden in tales of dropping seeds into damp earth beneath clouds that never lift. Names once forgotten now press against the page, demanding space. Each voice carries weight, though spoken softly across decades. Not memory alone keeps them present - it's the act of writing their words down that resists erasure. The past does not stay buried when someone insists on reading it aloud today.

7.Argument

It hits differently when you see conservation through the eyes of people actually living in the Sundarbans. Not policies made far away, but daily survival guides what works here. Because they face rising waters, their knowledge shapes better answers than outside experts might guess. When decisions come from those weathered by cyclones, fairness gets a stronger voice. You start hearing truth not in reports, but in stories told where land meets sea. Meaning grows quietly, rooted in moments most overlook. Recognition shifts when scholarship stops speaking over and starts walking alongside.

8.Findings

The lives of those in the Sundarbans unfold against layers of hardship - social, financial, still shaped by shifting tides. What stands out most? This area fits into what some call the hidden corners, almost another world tucked inside Asia. Left outside major progress talks, their voices slip through cracks. Beauty draws attention - the forests, the wildlife - but survival stories stay buried beneath it all.

Life gets tougher when nature turns harsh and communities already on the edge face even greater struggles. Cyclones strike often, water floods the land regularly, earth washes away slowly, seas creep higher each year - these shape daily existence here. Fishing boats capsize, crops drown under mud, trees vanish into rivers; what once fed families disappears overnight. With little left to hold onto, men and women head toward city lights hoping for jobs, leaving behind crumbling houses. Schools stay far off, clinics lack supplies, roads turn impassable after rain - all part of a pattern seen across these islands. When storms pass through, they leave more than wreckage - they deepen old gaps long before wind ever arrived. Few chances to grow socially or economically come up because of these barriers. Stuck, life stays fragile and pushed aside here. Mostly, what stands out is how the Sundarbans isn't just rich in nature. Instead, lives here bend under ongoing exclusion and being overlooked. Realizing this shapes better ways forward for fairer progress.

Field data from the distinct most remote villages and islands of Tushkhali, Dhamakhali, Bouthakurani, Jeliakhali (Sandeshkhali-II Block), Ghoramara (Sagar Block), and Garanbose, Nafarganj (Basanti Block) disclose deep marginality, aligning strongly with Fourth World characteristics:

1. Marginality and Structural Exclusion - These islands function as **'internal peripheries' through geographical isolation** creates administrative distance; **Frequent environmental shocks; can't take as usual access to healthcare, education, and transport; Seasonal migration**.

2. Livelihood Insecurity - The study identifies **multi-dimensional poverty**, not merely income-based on more dependence on **natural-resource-based livelihoods** from fishing, crab collection, honey gathering; Increasing **ecological degradation refers declining productivity;** Expansion of **informal and risky work** like forest entry, illegal resource extraction; Women's unpaid labor remains **economically invisible which are** linking directly with *Political Ecology* and Fourth World marginalization.

3. Distinct socio-cultural practices – Although not officially classified as 'indigenous' in all cases, these groups demonstrate **functional indigeneity** through ecological-cultural embeddedness. It includes strong belief in forest deity; Oral traditions, folklore, and **localized ecological knowledge systems.**

4. Lack of Sovereignty and Political Voice **-** citizenship exists formally but not substantively. It is proved by less participation in governance structures; Panchayati Raj institutions exist but are often ineffective or elite-controlled or authoritative party voice, Weak representation in policy decisions regarding climate adaptation, costal rights and land rights. This reflects a 'democratic deficit'.

5. Land Insecurity and Displacement - Riverbank erosion, tenure insecurity and submergence frequently displace households; Rehabilitation policies are often inadequate or delayed or irrelevant. Stateless-like conditions within the state make a core Fourth World feature.

6. Resistance to Assimilation and Local Agency – Governance gaps in indigenous vs. exogenous thought especially cultural disconnection about mangrove ecology; Most policy makers bring non indigenous knowledge , current alternative development makes internal displacement which is not sundarbans oriented; Formation of **Self-Help Groups** among women only, not for common; Informal resistance to exploitative labor and middlemen systems. These practices may be a symbol of **subaltern agency** and challenge the idea of passive marginality.

7. Exclusion from the Global Economy - Minimal incorporation into proper markets; Dependence on **local intermediaries and exploitative pricing;** Limited access to **digital infrastructure and financial inclusion. It** remains **peripherally linked**, not equitably integrated into universal economic systems.

8. Feminist Ecology Insight - Fourth World marginality is **deeply gendered.** Women face **triple burden** from economic, domestic, and environmental; Women face more internal diseases continuously from saline water based activities; Increasing feminization of poverty due to **male migration;** SHGs provide partial empowerment but remain **resource-constrained.**

9.Result

The study adopts an interdisciplinary analytical framework combining Political Ecology, Marginality Theory and Fourth World Studies. Political ecology helps to examine the power relations embedded in environmental governance, while marginality theory explains how certain populations are pushed to the edges of economic and political systems. Fourth World Studies further contextualizes communities that remain excluded from dominant development narratives despite being located within sovereign states (Rao and Reddy 2013).

Expectations run high that this work will sharpen insight into hardship and daily survival in the Sundarbans. Because hardships pile up, lives get shaped by forces beyond individual control. When society overlooks certain groups, their voices fade - this project aims to pull them forward. With clearer evidence, those shaping policy might finally turn their eyes toward forgotten corners. Awareness could grow, possibly sparking shifts in how aid, planning, and resources flow to vulnerable shores.

10.Policy Suggestion

In the first place, if government makes the bridges over the narrow channelized rivers, even embankments are maintained on a regular basis, the damage may be minimized.

Secondly, the people of disremote areas and islands should be taught and trained properly. In the above areas, roads should be repaired regularly and the conditions of the schools should be improved. In the said locality, the Doctors and the nurses should be available as much as possible and practicable. A sea change should be brought about in water transportation. Efforts should be engaged so that the doctors and the nurses may reach the patients at the hour of crisis.

Thirdly, job opportunities should be created among the local people so that they may earn their livelihood. Trainings should be organized frequently for skill development in growing food, fishing, honey collecting and welcoming the tourist in an appropriate manner. It should be ensured at the same time that the biodiversity of the locality will remain unchanged and undisturbed.

Fourthly, administrative contacts, representation in governance policy should confirm from indigenous peoples who know the sundarbanian ecology because all are not sundarbanians if lived in sundarbans region.

Finally, the government should come forward to protect the environment and the climate of the locality properly. At the same time local people should be involved in good number to protect the mangrove forests and the conservation of the forests as the local property.

12.Conclusion

Hidden corners of life come into view when we look closely at what most overlook. Far from city centers, across Asia, villages sit untouched by progress. Cut off from support, their days unfold without reliable institutions, markets or clinics. Hardship shapes routines where survival takes effort every day. Forgotten by policy makers, these groups face challenges others rarely see. Limited chances define existence for many born into such settings. J.P.Mondal (2025) points out how silence surrounds their struggles. Even when big conversations happen, silence often surrounds them, so their problems are hidden. What they are facing, it is necessary to look closely. Who live in the niche of Sundarbans; live in edges of sundarbans - ignored too, much like others on society's edges. Beauty and wild life mark that region, yet behind it runs hardship. Each day brings struggle, even where nature seems untouched. Floods, cyclones, and climbing seas hit this area again and again. Hard times pile up there - money struggles mix with weak paths and shelters, these areas of real existence in the Sundarbans are fighting just to stay alive in searching the sense of sundarbanian cultural ecology (Mondal 2024). Looking at life on the edges here reveals that being cut off by land plus facing constant cultural threats pushes communities out of mainstream progress. Life in the Sundarbans rarely appears in countrywide planning, despite residents' quietly holding together one of nature's most delicate systems. That said, officials, planners and scientists might do well to shift focus toward places like these. Thoughtful growth strategies, sturdier planning, research institutions within reach, and care for mangroves in the blue carbon economy matter deeply here.

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INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD
ISSN(O): 2455-0620 [Impact Factor: 9.47]
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value : 86.87
Volume - 12, Special Issue – 66, March - 2026, Publication Date: 31/03/2026

DOIs:10.2015/IJIRMF/ICRI-2026-P10 --:-- Research Paper / Article / Review

International Conference on Research and Innovations (ICRI-2026)
Date : 27 - 28 March, 2026

The Fitness Paradox in India: How Regular Exercise Protects Yet Acute Exertion Kills Young Athletes

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Abstract: *India is experiencing a disturbing rise in heart attacks among young, active individuals, prompting urgent examination of contributory factors. This narrative review investigates three interrelated domains: (1) Recent Lifestyle Changes, (2) Sudden Intense Exercise, and (3) Benefits of Regular Exercise. We synthesize Indian and global data to clarify why even fit youth are at risk. Recent cultural shifts—urban sedentary jobs, processed diets high in fats/sugars, stress, and energy-drink use—have increased obesity, hypertension, and metabolic disorders in Indians younger than 50. Concurrently, case studies and epidemiological research show that abrupt, vigorous physical exertion (e.g. intense matches or workouts) can acutely trigger myocardial infarctions or arrhythmias, especially in those with hidden cardiovascular disease. In a typical scenario, an otherwise healthy "weekend warrior" who is unaccustomed to intense training faces a much higher acute heart risk than a regularly conditioning athlete. Crucially, however, our analysis reaffirms that habitual moderate exercise dramatically reduces long-term cardiovascular risk, improving blood pressure, lipid profiles, and stress resilience. We discuss how sports teams and coaches can translate these insights: implementing graded training programs, pre-exercise health screening, and emergency preparedness (AEDs/CPR) to mitigate risks. By balancing enthusiasm for vigorous sport with strategic health measures, athletes and sports authorities can harness exercise's protective effects. We conclude that tailored guidelines and further research are needed to safeguard India's young sports community against preventable cardiac events.*

Keywords*: High-Intensity Exercises, Sedentary Lifestyle, Preventive Cardiology, Cardiovascular Disease*

1.INTRODUCTION

In recent years India has witnessed an alarming rise in heart attacks among young, seemingly fit individuals, including sports enthusiasts. Official data highlight this trend: in 2022 India recorded 32,457 heart-attack deaths – a 12.5% increase over the previous year – with roughly half of these victims being men under 50 and about a quarter under 40 (pmc.ncbi.nlm.nih.gov). Even teenagers and young adults have been reported suffering fatal cardiac events (e.g. a 17-year-old girl in Indore and a 23-year-old trekker during a mountain climb (pmc.ncbi.nlm.nih.gov)). As a consequence, coaches, sports directors, and public health experts are questioning why young athletes and fitness enthusiasts are at grave cardiovascular risk.

This paper critically examines the intersection of sports/exercise and heart attacks, focusing on three areas: (1) lifestyle changes that elevate cardiovascular risk in modern times; (2) the link

between sudden, intense exercise and acute cardiac events; and (3) the protective effects of regular, moderate exercise. While regular exercise is well known to improve heart health, intense physical activity can trigger myocardial infarction (MI) or arrhythmias in susceptible individuals (pmc.ncbi.nlm.nih.gov) (pmc.ncbi.nlm.nih.gov). By reviewing medical and sports-science literature, we aim to clarify how recent lifestyles and exercise patterns contribute to the rising incidence of heart attacks among young adults, and to reconcile this with the benefits of physical activity. The analysis will adopt a sports-management perspective, emphasizing actionable insights for coaches, athletes, and sports organizations, while maintaining a formal academic tone.

Specifically, we will survey existing research (the Literature Review) on cardiovascular risk factors in India and globally, including studies of heart health in sports contexts. Next, we outline our conceptual Methodology, which integrates epidemiological data and conceptual modeling. The Analysis and Discussion then synthesizes findings on lifestyle risk factors, exercise triggers, and exercise benefits, discussing how they interact in sports settings. Drawing from this, we propose Recommendations for individuals, athletes, and sports/public-health authorities on mitigating heart attack risk. We conclude with a summary of key points and suggestions for future research.

2.Literature Review

Recent Lifestyle Changes and Cardiovascular Risk

Modern lifestyles have shifted markedly over the past decades, and these changes are increasing cardiovascular risk even among the young. In India, urbanization, dietary westernization, and sedentary habits are contributing to a surge in traditional risk factors. National surveys show dramatic trends: for example, data from the National Family Health Survey rounds (2005–21) reveal a doubling of overweight/obesity among 15–49 year-olds (from ~11% to 23.6%) and rising prevalence of hypertension and diabetes (pmc.ncbi.nlm.nih.gov). Conversely, tobacco and alcohol use have declined during the same period (pmc.ncbi.nlm.nih.gov). The upshot is that older “lifestyle” risk factors (smoking, alcohol) are waning, while obesity, sedentary behaviour, and metabolic issues are climbing – a pattern mirrored across India’s states (pmc.ncbi.nlm.nih.gov).

Prolonged sedentary time – common in modern desk and screen-based work – independently raises heart risk. Meta-analytic data indicate that each additional hour of daily sitting increases all-cause mortality by ~2% (implying ~34% higher mortality for 10 hours of sitting) (pmc.ncbi.nlm.nih.gov). Indians now spend roughly half of each day sedentary (pmc.ncbi.nlm.nih.gov). Such inactivity contributes to obesity, hypertension, and dyslipidemia. Less physical work, more processed food intake, and higher stress levels have created a cardio-toxic environment. For instance, urban stress and unhealthy diets (high salt, sugar, and trans fats) underlie trends of elevated blood pressure and blood sugar in youth (pmc.ncbi.nlm.nih.gov) (pmc.ncbi.nlm.nih.gov).

In addition to diet and inactivity, novel lifestyle factors have emerged. Energy drink and supplement use is popular among gym-goers and athletes, yet it carries risks. Case reports link energy-drink consumption in healthy young adults to out-of-hospital cardiac arrest (likely from hypertension, platelet effects, and arrhythmia) (pmc.ncbi.nlm.nih.gov). One editorial recounts two young men who suffered cardiac arrest after energy drinks, underscoring that “caffeine and other ingredients likely affected the sympathetic and cardiovascular systems” (pmc.ncbi.nlm.nih.gov). Similarly, the abuse of stimulants or unregulated bodybuilding supplements can induce arrhythmias or MI. Another factor is insufficient sleep and high stress – the Indian Heart Association notes that chronic stress and irregular lifestyles (“all work, no play”) may contribute to earlier heart disease onset (pmc.ncbi.nlm.nih.gov).

Quantitatively, heart attack cases in India have spiked. The National Crime Records Bureau (NCRB) reported 32,457 heart-attack deaths in 2022 (pmc.ncbi.nlm.nih.gov). Notably, an estimated *half* of heart attack victims are men under 50, and about one-quarter are under 40 (pmc.ncbi.nlm.nih.gov). Pediatric and adolescent heart attacks, while rare, are also reported (e.g. fatal MI in teenagers after infection or acute stress (pmc.ncbi.nlm.nih.gov)). Seasonal and event-related patterns have been observed: for example, Navratri festival dancing (garba) coincided with peaks in cardiac emergencies, as Gujarat’s

emergency services saw a 55% jump in heart-attack calls in Oct–Nov 2023 (pmc.ncbi.nlm.nih.gov). These trends underscore that a lipid-rich diet, obesity, smoking, and inactivity are colliding with acute stressors to produce heart attacks even in young Indians.

Sudden Intense Exercise as a Trigger

While chronic risk factors build a foundation for disease, acute bouts of intense exercise can act as immediate triggers for heart attacks in predisposed individuals. It is well-established that vigorous exertion transiently raises the risk of myocardial infarction (MI) or sudden cardiac death (SCD), especially in people with underlying pathology. Classic studies and reviews note that sudden exertion precipitates events: for example, Vikström *et al.* followed 192 men in Sweden who suffered SCD due to MI. They found that 24 of these cases occurred during or within 30 minutes of vigorous exercise, giving a relative risk of ~43.6 compared to non-exercise periods (pmc.ncbi.nlm.nih.gov). Crucially, the risk was *highest* (RR≈107) among those who were habitually inactive, but it was markedly lower in men who exercised regularly (pmc.ncbi.nlm.nih.gov). In other words, a sporadic heavy workout posed a far higher acute risk than the same exercise done by a fit individual. This case-crossover evidence demonstrates that instantaneous heart strain during intense activity can rupture plaques or trigger lethal arrhythmias (pmc.ncbi.nlm.nih.gov).

Amateur sports also carry risk. A recent scoping review of sudden cardiac death in leisure athletes (soccer, running, etc.) identified intense physical exertion as a common precipitant (pmc.ncbi.nlm.nih.gov). Underlying causes were often undiagnosed: in younger athletes, cardiomyopathies or myocarditis; in older amateurs (>35), atherosclerotic coronary disease (pmc.ncbi.nlm.nih.gov). Male sex and the lack of on-site defibrillation also correlated with SCD in sports settings (pmc.ncbi.nlm.nih.gov). In real-world events globally (including India), even apparently healthy young athletes have collapsed during activity. For example, the literature cites that hidden congenital anomalies of coronary arteries or electrical channelopathies (e.g. long QT syndrome) may only surface under the stress of hard effort (pmc.ncbi.nlm.nih.gov) (pubmed.ncbi.nlm.nih.gov). The editorial *"Young Hearts under Attack"* notes that arrhythmias associated with hypertrophic cardiomyopathy or anomalous coronaries can be triggered by physical exertion and cause sudden death if unaddressed (pmc.ncbi.nlm.nih.gov).

Environmental factors during exercise amplify risk. Dehydration, electrolyte imbalances, heat stress, or altitude can exacerbate cardiac strain. The case of a 23-year-old Indian trekking enthusiast highlights this: after hiking to the peak of Tadiandamol (Kodagu), he collapsed from a "severe heart attack" (pmc.ncbi.nlm.nih.gov). Factors like cold weather or previous illness (even mild infections) can further destabilize the heart. Moreover, trauma-related SCD (commotio cordis) – though rare – is a sports phenomenon where a blunt chest blow during play induces ventricular fibrillation (pubmed.ncbi.nlm.nih.gov). Even chest impacts in cricket or baseball have caused instant cardiac arrest in young athletes.

In summary, acute high-intensity exertion greatly increases the immediate risk of MI or SCD, especially if undertaken by someone with cardiovascular risk factors or unknown cardiac pathology. This does not imply that exercise is bad per se; rather, it underscores that the context and timing of exertion matter. Indeed, Vikström et al. emphasize that while *vigorous exercise* itself is a trigger, habitual training blunts this risk (pmc.ncbi.nlm.nih.gov). Thus, a "weekend warrior" who has been largely sedentary but then engages in a marathon or heavy weightlifting session faces a much higher instantaneous risk than a regular athlete performing the same activity.

Health Benefits of Regular, Moderate Exercise

Paradoxically, the very solution to cardiovascular risk is often regular, moderate exercise. Consistent physical activity produces broad protective effects on the heart and vessels, outweighing the rare triggers. There is a vast literature documenting that people who meet exercise guidelines have lower incidence of heart disease and mortality. For example, a Spanish cardiology review concludes that *"performing physical activity of moderate intensity for a minimum of 30 min 5 days a week...*

improves functional capacity and is associated with reductions in the incidence of cardiovascular disease and mortality." (www.revespcardiol.org). In concrete terms, achieving ≥150 minutes per week of moderate aerobic activity (or equivalent vigorous exercise) can dramatically reduce cardiovascular events. In one notable study, elite endurance athletes (e.g. Tour de France cyclists) had 33% lower cardiovascular mortality than the general population (www.revespcardiol.org).

Mechanistically, regular exercise favorably shifts many risk factors. Aerobic training reduces resting blood pressure, improves endothelial function, enhances insulin sensitivity, and increases "good" HDL cholesterol. A recent meta-analysis of randomized trials showed that just 30–40 min/session, 3–5 days/week of exercise in previously sedentary adults significantly lowered systolic and diastolic blood pressure and resting heart rate (pmc.ncbi.nlm.nih.gov). While that review found no significant changes in cholesterol or BMI (likely due to short duration), the blood pressure reductions alone correspond to lower stroke and MI risk. Long-term, fit individuals tend to have less hypertension, obesity, and diabetes. In the Elixir of Life, exercise has often been likened to a "polypill" for the heart.

Beyond pure physiology, exercise also confers psychosocial benefits that indirectly protect the heart. Regular physical activity is linked to less depression and stress, better sleep, and improved quality of life (pmc.ncbi.nlm.nih.gov). A German cohort study found that active adults had a "more favorable cardiovascular risk profile, better quality of life, and less psychological stress" than sedentary peers (pmc.ncbi.nlm.nih.gov). These factors—lower stress hormones, better mood, greater social engagement from team sports—likely contribute to cardiovascular resilience. In fact, cardiovascular adaptations from training (e.g. larger stroke volume, more efficient heart muscle) enhance overall physiological poker, making transient stressors less lethal.

Crucially, the literature stresses that *most* people (and athletes) benefit vastly more from the protective effects of habitual exercise than they are harmed by rare triggers. The review by Han *et al.* (2023) emphasizes that the benefits of exercise for cardiovascular health are many, while SCD events in athletes remain extremely rare (pubmed.ncbi.nlm.nih.gov). Only individuals with specific underlying conditions are at markedly higher risk during exertion. In practical terms, consistent moderate exercise (e.g. brisk walking, cycling, swimming) provides a strong net reduction in heart attack risk, whereas sudden all-out exertion without preparation can be dangerous.

3.Methodology

Given the broad scope of this analysis, the methodology is primarily a narrative review and conceptual synthesis of existing evidence. We surveyed peer-reviewed studies, editorials, and guidelines spanning cardiology and sports medicine. Searches were conducted on databases like PubMed and Google Scholar (no date restrictions) using keywords such as *"sudden cardiac death athletes"*, *"exercise myocardial infarction"*, *"India heart attack young"*, and *"physical activity cardiovascular risk."* Indian-specific data were obtained from national surveys (e.g., NFHS) and governmental reports cited in open-access literature. Although some news sources (e.g. Times of India) informed context, we prioritized academically vetted publications and official statistics.

No new clinical trial or cohort data were generated; rather, this is a secondary research work. We abstracted quantitative findings (e.g. incidence rates, relative risks) to illustrate points, always noting the study design. For example, Vikström et al.'s case-crossover study (pmc.ncbi.nlm.nih.gov) provides an empirical basis for discussing acute exercise risk, illustrating how to evaluate exertion as a transient exposure. Methodologically, one could likewise conduct observational studies in India: for instance, analyzing emergency-room logs for timing of heart attacks relative to sports events, or comparing heart health profiles of gym-goers versus couch potatoes. In absence of such data here, we extrapolate from international studies and propose frameworks.

Analytic reasoning was used to integrate sports perspectives. For example, to gauge how sports training influences heart health, we considered theoretical concepts like the *acute:chronic exercise load ratio* from sports science, which suggests that sudden jumps in activity (acute load) relative to baseline (chronic load) raise injury risk. Similarly, we applied knowledge of sports regulations (like the

American College of Sports Medicine's preparticipation screening guidelines (journals.lww.com)) to frame practical implications. In sum, the approach is interdisciplinary: combining epidemiological data on Indian population risk factors, pathophysiological mechanisms of exercise-induced cardiac events, and principles of sports training and safety.

4.Analysis and Discussion

The convergence of modern lifestyles and sports participation creates a complex interplay affecting heart health. On one axis, increasing obesity, diabetes, and hypertension among young Indians (pmc.ncbi.nlm.nih.gov) set the stage for earlier coronary disease. On another axis, rising fitness culture encourages vigorous training and competition. This intersection can be visualized as follows: longstanding risk factors (poor diet, sedentarism, genetics) accumulate subclinical coronary atherosclerosis or myocardial scarring, while a trigger event (e.g. a heavy workout, a match) provides the stress needed to precipitate an acute MI or arrhythmia. This two-hit model is evident in many case reports of fit young adults collapsing out of the blue.

From a sports-management viewpoint, consider a local cricket or football team: their players might train vigorously once or twice a week, spending the rest of the time inactive behind screens or desks. Without frequent conditioning, a sudden high-stakes match becomes a perilous spike in exertion. Vikström's finding (RR≈107 in untrained men) implies that training habits dramatically modulate risk (pmc.ncbi.nlm.nih.gov). In practice, sports directors must recognize that players who are "weekend warriors" by training schedules are the most vulnerable during intense games. Conversely, athletes who train regularly build up protection: cardiac adaptations (bigger volume chambers, stronger vessels) buffer the heart against sudden stress.

Coach and trainer roles are crucial. Pre-activity conditioning (warm-ups, gradual skill drills) help prepare cardiovascular and musculoskeletal systems. Indeed, athletic training protocols often include incremental intensity sessions; this intuition aligns with the science. For example, Amit Vora *et al.* (2017) explicitly recommend a "supervised, graded exercise regime" for older or novice sports participants in India (pmc.ncbi.nlm.nih.gov). This means starting with low intensity and slowly ramping up workload, much like marathon training schedules. Similarly, instructors should teach athletes to recognize warning signs (excessive fatigue, chest discomfort, unusual palpitations) and to abstain from strenuous exertion if unwell (e.g. recovering from illness) (pmc.ncbi.nlm.nih.gov) (pmc.ncbi.nlm.nih.gov).

Evidence from sports cardiology underscores these practices. Banerjee (2025) notes that pre-participation screening (PPS) can catch hidden cardiac disorders that lead to SCD (pmc.ncbi.nlm.nih.gov). For sports teams, this translates to periodic health evaluations: medical history, physical exam, and possibly ECG. Many countries mandate PPS for competitive athletes; although India has no universal requirement, the concept is gaining acceptance. For instance, elite school or college teams could adopt basic screening similar to the American Heart Association's guidelines (pmc.ncbi.nlm.nih.gov) (journals.lww.com). Even non-athletes who engage in gym workouts could benefit from a wellness check.

On the other hand, it is vital to balance the picture: sports should not be avoided out of fear. The benefits of exercise are profound. Regular moderate exercise promotes favorable cardiac remodeling, improved autonomic balance (lower resting heart rate), and reduced arterial stiffness (www.revespcardiol.org). These adaptations mean that during submaximal or moderate activities, the heart works more efficiently. Functionally, an aerobically trained athlete has a higher cardiac output that can be sustained safely; they also tend to have less aggressive plaque buildup. As one sports cardiology review states, only in "extreme cases" does exercise-induced adaptation become maladaptive; otherwise, exercise is protective (www.revespcardiol.org).

Importantly, in a sports setting the *context of activity* influences risk. Competitive matches often involve bursts of high-intensity exertion, but also periods of low activity. Structured training (drills, sprints, agility) differs from unstructured exertion (sudden sprint after sitting). The incidence of heart events is

likely higher when the body is unprepared for abrupt strain. For example, marathoners who train irregularly may face dangers at checkpoints when adrenaline surges after hours of exertion. Sports organizations should emphasize consistent aerobic conditioning to mitigate this. Encouraging athletes to maintain a baseline level of activity (even simple jogging or non-competitive drills) is akin to lowering their relative "acute:chronic load," thereby reducing the trigger effect.

We must also consider non-exercise cardiac events that can mimic sports-related causes. Some collapses during sports are due to non-atherosclerotic causes like myocarditis or coronary anomalies which might not be preventable by fitness per se. Nonetheless, even then, being healthier overall affords better resilience. And when a cardiac arrest does occur, response protocols are crucial. Team settings provide an opportunity: training coaches and staff in CPR and having automated external defibrillators (AEDs) on-site can save lives. In fact, prevention of SCD in sports relies heavily on rapid resuscitation – the minutes between collapse and defibrillation often determine survival (pmc.ncbi.nlm.nih.gov). This operational aspect falls under sports management and public health planning, confirming that the "sports angle" includes emergency preparedness.

In summary, the analysis highlights a "double-edged sword" of exercise. On one edge, modern sedentary lifestyles inflict a heavier cardiovascular burden that makes any sudden exertion potentially dangerous. On the other edge, regular, structured exercise is the principal remedy – it improves all metabolic and hemodynamic parameters of heart health. The goal for athletes and sports directors is to lean on the benefits while carefully managing the risks. Putting it succinctly: maximize cumulative exercise adaptation, minimize unaccustomed strenuous bursts. This integrated view is the cornerstone of sports cardiology practice.

5.Recommendations

Building on the above insights, we propose the following evidence-based actions aimed at athletes, coaches, sports organizations, and public health authorities:

1. **Athletes and Individuals:**
    i) Engage in **regular moderate exercise** (e.g. brisk walking, jogging, cycling) totaling at least 150 minutes per week, as recommended by cardiovascular guidelines (www.revespcardiol.org). Even if time-constrained, accumulate exercise in shorter bouts throughout the week.
    ii) **Gradually increase intensity**. Avoid sudden intense workouts if you have been sedentary. Warm up thoroughly before high-intensity activity to prepare the heart and muscles.
    iii) **Screen for judgmental expenses**: undergo periodic health check-ups, especially if planning heavy training. Even young adults should obtain an annual physical that includes blood pressure, cholesterol, and basic cardiac evaluation. Consider an ECG if you have any risk factors (family history, chest symptoms, hypertension).
    iv) **Listen to your body**. Do not push through warning signs like unusual chest pain, excessive breathlessness, or palpitations. Stop exercise if feeling faint or sick. Athletes should refrain from intense training when ill (fever/viral infections), aligning with sports medicine advice (pmc.ncbi.nlm.nih.gov).
    v) **Maintain a heart-healthy lifestyle**. Adopt a balanced diet (low in trans fats, salt, and sugars) and avoid smoking or excessive alcohol. If overweight or diabetic, consult a doctor for management. These measures reduce baseline risk so exertion is safer.
    vi) **Avoid stimulants and unregulated supplements**. Be cautious with energy drinks, pre-workout supplements, or performance enhancers that can raise heart rate and blood pressure. Recent cases link energy drink overdose to arrhythmias

(pmc.ncbi.nlm.nih.gov). Use only tested sports supplements under professional guidance.

vii) **Monitor training load**. Use wearable devices or heart-rate monitors if possible to track intensity. Aim for moderate heart rate zones most of the time, and only rarely reach maximal exertion.

2. **Coaches, Trainers, and Sports Organizations:**

i) Implement **pre-participation cardiovascular screenings** for competitive athletes. This should include a detailed history (family heart diseases, fainting during exercise) and physical exam. Where resources allow, a resting ECG can be very effective at detecting silent conditions (pmc.ncbi.nlm.nih.gov) (pmc.ncbi.nlm.nih.gov). In India, even basic screenings can help; for example, trainingcamp healthcare protocols might require a doctor's clearance for new players.

ii) Enforce **graded training programs**. Novice or aging athletes should follow a supervised, incremental training plan that slowly builds endurance and strength (pmc.ncbi.nlm.nih.gov) (pmc.ncbi.nlm.nih.gov). For instance, senior players or recreational runners should not jump into full-distance games or marathons without months of preparation. Sports directors should tailor regimens to individual fitness levels.

iii) Provide **emergency preparedness** at sporting venues. All training grounds and matches should have at least one AED accessible and personnel trained in CPR. Time to defibrillation is critical for survival in SCD (pmc.ncbi.nlm.nih.gov). Quick response plans (e.g. designated first-responder, ambulance access) can save lives when collapse occurs on the field.

iv) **Education and awareness**: Train athletes and staff on heart-attack symptoms (chest pain, jaw/arm discomfort, unexplained sweating) and the importance of reporting them promptly. Destigmatize taking rest if feeling unwell during practice. Reinforce that acknowledging risk is prudent, not cowardly. Coaches can hold regular "safety meetings" to review such protocols.

v) **Encourage healthy team lifestyles**. Create an environment that promotes complete cardiovascular health: team-provided nutritious meals (fruits, vegetables), scheduled recovery days, and discouragement of risky behaviors (smoking, binge drinking). Some clubs have wellness counselors or in-house dietitians for this purpose.

vi) **Monitor training volumes**: in-season and off-season schedules should balance workload and rest. Sudden spikes in training (e.g. going from no training to intense camp) should be avoided. Sports scientists often use metrics like acute:chronic workload ratios to flag dangerous increases; coaches can apply similar principles (e.g. not more than 10% weekly mileage increase for runners).

vii) **Policy and advocacy**: Sports governing bodies (state and national federations) should consider mandatory basic screening and clear guidelines for training loads. For example, the Cardiological Society of India recommends PPS and graded exercise for marathoners and athletes (pmc.ncbi.nlm.nih.gov). Similar policies could be adopted in Indian leagues and school sports.

3. **Public Health and Policy Makers:**

i) **Promote nationwide fitness** through public campaigns and urban planning. Encouraging daily moderate activity (e.g. walking or cycling infrastructure) will improve citizens' baseline cardiac health. This long-term shift reduces the pool of at-risk individuals.

ii) **Regulate stimulant marketing**. Given the cardiovascular dangers, consider tighter controls on high-caffeine energy drinks and certain supplements. Label warnings and age restrictions could be implemented to prevent misuse among youth.

iii) **Support research and surveillance**. Invest in tracking cardiovascular health trends in young Indians, and fund studies (possibly large cohorts or registries) on exercise and heart events. Data on Indian athletes' heart outcomes would guide tailored interventions.

By following these recommendations, individuals and organizations can achieve a balance: leveraging exercise for its health gains while minimizing the chances that strenuous activity becomes a trigger for catastrophe.

6.Conclusion

The increasing incidence of heart attacks among young people in India — even those active in sports — is a multifactorial issue. This review found that a combination of adverse lifestyle trends (sedentary behavior, poor diet, stress, substance use) and acute physical stressors (sudden vigorous exercise) is contributing to early cardiac events. The good news is that regular, moderate exercise remains a powerful countermeasure: it directly improves blood pressure, lipid and metabolic profiles, and indirectly reduces stress and inflammation (www.revespcardiol.org) (pmc.ncbi.nlm.nih.gov). In contrast, unaccustomed intense exertion can induce plaque rupture or arrhythmias on top of pre-existing damage (pmc.ncbi.nlm.nih.gov) (pmc.ncbi.nlm.nih.gov). Thus, we must not demonize exercise but instead educate on *how* to exercise safely.

For sports authorities and coaches, the implication is clear: incorporate cardiovascular screening and safety protocols into athlete management, and emphasize consistent conditioning over sporadic intensity. The sports field can and should be a safe space for physical activity. That means being proactive (health education, screenings, AEDs) and reactive (CPR training) in equal measure. It also means acknowledging that even the fittest athlete may harbor hidden risk factors, so a culture of caution and health-awareness is essential.

Future research should explore the nuances of this problem in India's context: for example, longitudinal cohort studies of young adults' exercise habits and cardiac events, or intervention trials (e.g. implementing screening programs in school sports and measuring outcomes). Further work on genetic and acquired risk factors in Indian athletes could also help tailor prevention. Meanwhile, collaboration between cardiologists, sports scientists, and coaches is vital to continually update best practices.

In sum, "Sports and Heart Attacks" is not a contradiction but a call for informed balance: to enjoy the *profound* benefits of physical activity while respecting the limits of our cardiovascular system. By doing so, we can help ensure that sports and exercise remain lifelong allies in health – not sudden enemies.

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